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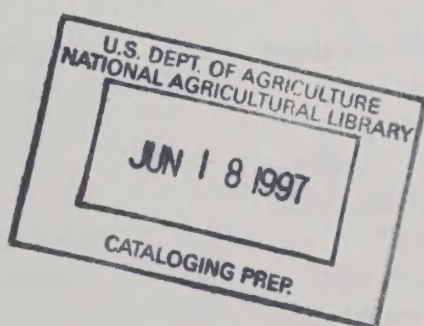Department of
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Identifying Germplasm for Successful Forage Legume-Grass Interactions

Proceedings of a Symposium of the Crop Science Society of America, November 14, 1994, Seattle, Washington

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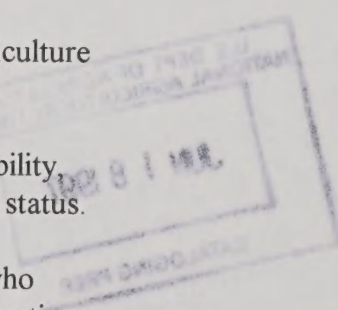
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PREFACE

This symposium was held on November 14, 1994 at the annual meeting of the Crop Science Society of America in Seattle, Washington. It was entitled "Identifying Germplasm for Successful Forage Legume-Grass Interactions." The symposium was jointly sponsored by Division C-1, Crop Breeding, Genetics, and Cytology, Division C-6, Crop Quality and Utilization, and Division C-8, Plant Genetic Resources. Speakers in this symposium addressed methods and techniques for evaluating tropical and temperate legume and grass germplasm to select species which form compatible associations. Genera and topics covered in the papers included *Alysicarpus, Arachis, Desmodium, Desmanthus, Kummerowia, Lespedeza, Lotus, Macroptilium, Medicago, Paspalum, Trifolium, Vigna*, plant pathological aspects of grass-legume interactions, grass-legume competition aspects, and roles and importance of legumes in forage livestock systems. The papers presented herein should be of particular interest to forage researchers and individuals interested in sustainable agricultural systems, since forage-livestock systems containing legumes are a vital component of sustainable agricultural systems.

ALTERNATIVE FORAGES FOR THE TROPICS: *ARACHIS* AND *PASPALUM*

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ABSTRACT

A summary of the available information on agronomic attributes, seed production, disease and pest resistance, drought tolerance, nutritive value, animal performance, and alternative uses of forage *Arachis* spp. and *Paspalum* spp. was presented. Dry matter (DM) forage yields of *Arachis* spp. have been recorded in seasonally flooded land and well-drained savannas of tropical America. DM yields for forage *Arachis* ranged from 2.5 to 13 t/ha in the Brazilian lowlands, 0 to 500 kg/ha DM during the rainy season in the LLanos of Columbia, and 0 to 3 t/ha in the humid tropics. Pure seed yield varied from 0 to 5 t/ha at 14 months after planting. The DM yield in the *Paspalum* collection reached 29 t/ha in the Brazilian lowlands vs. 18 t/ha in the Cerrado. Pure seed yield ranged from 0 to 1.5 t/ha. Nutritive value, as measured by *in vitro* dry matter digestibility (IVDMD) varied from 30 to 64%, but was similar to other commercial grasses. Animal live weight gains of 760 g/hd/d were recorded on a pasture of *Paspalum atratum* Swallen (BRA 9610) and *Arachis pintoi* Krap. et Greg. (BRA 31143) at CPAC, Planatina, Brazil. In addition, alternative uses of *A. pintoi* as a ground cover in various plantations crops was also presented.

INTRODUCTION

Although *Arachis* and *Paspalum* species occur widely in the southern cone of South America (Valls 1992 a, b, and c, Valls and Pizarro 1993) and are recognized for their forage value in Australia, Colombia, Costa Rica, Honduras and the USA, they have not been deliberately propagated for forage in South America like other "foreign" or "exotic" grasses and legumes. This paper reviews the available data on evaluation, adaptation to climate and biotic constraints, present and potential agronomic use, suitability for different farming systems, limitation for adoption, and priorities for research and development on newly collected germplasm of the forage legume *Arachis pintoi* and selected species of the grass genus *Paspalum*.

ARACHIS SPECIES

Agronomic Performance of Forage *Arachis* across Ecosystems

Evaluation of wild populations

Three wild *Arachis* populations have been regularly monitored since 1991. The first population is a natural association of *A. pintoi* (BRA 15121) and *Hyparrhenia rufa* (Nees) Stapf located in the State of Goias, Brazil (15° 26'S, 47° 21'W at 700 m). This population has averaged 10.9 t DM/ha/yr. The legume was stable over time, averaging 13% of the stand and producing a soil seed-bank reserve of 330 kg seed/ha. The nutritive value of the legume averaged 70% IVDMD and 22% crude protein (CP). The grass averaged 54% IVDMD and 8% CP (Table 1). A second population is a pure stand of *Arachis sylvestris* (A. Chev.) A. Chev. (BRA 13423) also located in the State of Goias, Brazil (15° 13' 21" S and 47° 09' 52" W at 570 m). This dense and healthy community averages 140 ± 58 plants/m^2 and a soil seed-bank reserve of 2.5 ± 0.2 t/ha (Table 2). The third population is a mixture of *Arachis repens* Handro (BRA 14788), *Brachiaria arrecta* (Hack. ex T. Durand Schinz) Stent and *Paspalum* spp. located in the State of Minas Gerais, Brazil (17° 09'S, 44° 39' W at 500 m). The animal live weight gain for one year of grazing on this population was 200 kg/ha. These natural populations illustrate the usefulness of *Arachis* spp. for forage.

Savannas and Humid Tropics of Tropical America: *Arachis pintoi*

Agronomic evaluation of *A. pintoi* began in South America in 1976 at CIAT-Quilichao, Columbia (Grof 1985 a and b). Since then more than 48 agronomic trials have been carried out (Pizarro 1992, Argel 1993, Pizarro and Rincón 1993). A

brief summary of *A. pintoi* data will be reported for the main ecosystems of tropical America.

Llanos of Colombia

Between 1976 and 1992, most agronomic evaluations focused on *A. pintoi* (CIAT 17434). In relation to other legumes, its performance in regional evaluations were considered marginal to poor (Pizarro 1992). On the other hand, the performance of *A. pintoi* in association with grasses and under grazing was superior to that of other legumes (Lascano 1993). This encouraged researchers, the extension service, and advisory service of Colombia to release the accession as cultivar "maní forrajero perenne" (Rincón et al. 1992). This was contradictory to our experience in the LLanos of Colombia, between standard cutting trials in small plots vs. grazing experiments in association with a grass, which suggested that traditional evaluation procedures for legumes, especially for a stoloniferous legume like *A. pintoi*, needed to be questioned and urgently modified. Theses clipping experiments concluded that misleading results could be obtained due to the artificial nature of defoliation.

Brazilian Savannas "Cerrado"

The well-drained tropical isothermic savannas known as "Cerrado" occupy nearly 203 million ha or 22% of the Brazilian territory. Well-drained plains dominate, but are intersected with poorly drained lowlands that comprise 30% of the total area. *Arachis* germplasm was evaluated in the lowlands in 1987 (Grof et al. 1989c, Pizarro et al. 1993) and in the well-drained plains since 1991 (Pizarro and Rincón 1993). Special emphasis was given to these areas due the lack of available legume germplasm and a need for newer *Arachis* germplasm with faster establishment rates and drought tolerance. Several experiments are currently under way to determine if *A. pintoi* can survive the 4 to 6 month seasonal dry periods and associated high temperatures with low relative humidities. Preliminary results (1991-1994) indicated that *A. pintoi* (BRA 31143) can survive seasonal dry periods with considerable green leaf

retention and DM production. Green leaf percentage dropped from 38% in the middle of the dry season (July) to 15% at the end of the dry season (September). The forage yield in the dry season averaged 1.2 t DM/ha. Although yields are not as high as other forage, the yields ranged from 3.6 t DM/ha at the middle of the dry season to 1.0 t DM/ha near its end. The soil seed-reserve was 720 kg/ha at 18 months after planting.

The above observations prompted a series of investigations. In December 1991, eight *Arachis* accessions were established and evaluated in pure stands. Ground cover at 12 wks after planting ranged from 4% for *A. glabrata* Bentham (BRA 17531) to 46% for *A. pintoi* (BRA 31143). In the first year of study, total DM forage yield ranged from 1.0 to 4.4 t/ha. These species have excellent survival and rapid establishment characteristics. One year after vegetative establishment the percentage ground cover ranged from 100% for *A. glabrata* (BRA 17531) and *A. pintoi* (BRA 30082, 30261) to 218% for *A. pintoi* (BRA 31143).

Seasonally Flooded Land

A set of 33 accessions of different *Arachis* species, provided by CENARGEN (Centro Nacional de Pesquisa de Recursos Genéticos e Biotecnologia) was evaluated in 1990. In two years of evaluation, the accumulated total DM yield of 11 selected accessions ranged from 9 to 24 t/ha. Edible DM during the wet season ranged from 2 to 9 t/ha and in the dry season from 2 to 4 t/ha. (Pizarro et al. 1993, Pizarro and Rincón 1993). DM yield efficiency of selected accessions in relation to precipitation ranged from 2 to 7 kg DM/ha/mm in the rainy season to 12 to 23 kg DM/ha/mm during the dry season.

An important characteristic among species and accessions of the genus *Arachis*, section *Caulorrhizae* is the variation in rate of spread (ground cover). Among the selected accessions, percent ground cover ranged from 128 to 198% of their original size at 480 days after vegetative

establishment.

A second set of 48 accessions of *A. pintoi* and *A. repens* in association with *Paspalum atratum* (BRA 9610) has been evaluated since 1992 in the savanna and seasonally flooded land. Ground cover at 9 wks after planting varied from 65 to 100%. The most promising accessions one year after establishment were *A. repens* (BRA 31861) and *A. pintoi* (BRA 13251, 15121, 15598, 30449, 30546, 31135, 31143, 31828, 31836, 31844).

A third set of 80 *A. pintoi* accessions associated with *Brachiaria decumbens* Stapf (CIAT 16488) was recently established. Detailed data, such as growing capacity of primary, secondary, tertiary, etc. stems were recorded. Significant differences existed in the basal diameters and in the number of primary and secondary stems at 39 and 148 days after planting (Table 2). The mean daily growth of the primary stems within accessions was 5, 3, and 2 mm/day at 39 days of growth and 6, 5, and 3 mm/day at 148 days after establishment for *Arachis* accessions (BRA 31143, 13251, 15121), respectively.

Humid Tropics

The adaptation of *A. pintoi* (mainly CIAT 17434) in the humid tropics of South America was better than in the LLanos of Colombia. Its agronomic performance ranging from poor to excellent, DM yield was higher, and ground cover establishment was faster (Pizarro and Rincón 1993). In Central America and the Caribbean, agronomic performance was outstanding. DM yield ranged from 1 to 4 t/ha in a 12 wk growth period (Argel 1993). Other accessions besides CIAT 17434 have given promising results. For example in Ecuador, accessions CIAT 18751 and 18748, had better DM yield than CIAT 17434 (Pizarro and Rincón 1993). In the Central America, accession CIAT 18744 was outstanding (Argel 1993). In summary, *A. pintoi* grows well on a wide range of soils with textures varying from heavy clay to sand, but grows best in sandy loams with good moisture.

Agronomic Features: *Arachis pintoi*

Establishment

The slow establishment of *A. pintoi* (CIAT 17434) is well documented (Keller-Grein 1990, Pizarro 1992, Pizarro and Rincón 1993). Experiments to study the effect of fertility on the rate of establishment and yield are underway. Three accessions (BRA 15598, 31143, 31852) were planted in a red-yellow latosol to measure their response to phosphorous. When the level of P_2O_5 increased from 50 to 200 kg/ha the response in DM yield ranged from 72 to 116% (Vilela, L. personal communication).

Two additional trials, one with 48 *A. pintoi* accessions in association with *P. atratum* (BRA 9610) and another with 80 A. pintoi accessions in association with *B. decumbens* (CIAT 16488) were under evaluation. Significant variation was found for establishment periods for the newly collected germplasm.

A series of experiments with and without the aid of agronomic cultural practices was planned to select germplasm with rapid establishment rate. A recent experiment was conducted to measure the ground cover in four *A. pintoi* accessions. The four accessions (BRA 13251, 15598, 31143, 31852) were planted in a red-yellow latosol (4.5 pH, 1 ppm P and 0.81 meg. Al/100ml) by seed and vegetative material. Results clearly indicated that 12 wks after planting the ground cover in the seed-planted plots ranged from 30 to 63% while vegetative planted plots ranged from 14 to 46%. Twelve weeks after planting, the mean ground cover was 53 ad 28% for seed and vegetative propagation, respectively.

Annual species have been successfully used for pastures in regions with a pronounced summer and winter or a dry cold season. The persistence of these "drought-evaders" rests on adaptations that enable reproduction to

occur under grazing. Such is the case in nature with *Arachis* spp. Persistence of annual legumes is achieved through prolific seed production coupled with varying degrees of hard seededness (Martin and Torssel 1974, McKeon and Mott 1982). The persistence of wild annual peanut has been studied by Beaty et al. (1968). The agronomic practice with a mixture of annuals and perennial components is not new and it is really what nature offers to us (Rossengurt 1943).

In order to select germplasm of *Arachis hypogaea* L. as a partner for perennial *A. pintoi*, it was necessary to screen available germplasm. Five accessions of *A. hypogaea* selected by Dr. I. Godoy from the Instituto Agronômico de Campinas (IAC) at São Paulo State, were planted in a monoculture and in a mixture with five *A. pintoi* accessions. At 12 wks after planting *A. hypogaea* V-70 covered 100% of the soil, *A. pintoi* (BRA/CIAT 31343/22160) covered 63% of the soil, followed by *A. glabrata* (BRA 17531) with 4% ground cover.

Other agronomic characteristics, such as persistence, shade tolerance, and disease and pest resistance, are covered in the recent publication "Biology and Agronomy of Forage *Arachis*" (Kerridge and Hardy 1993). Drought tolerance will be discussed in more detail for the Cerrado because of the length of the dry period, the drop in temperature at night, and the low relative humidities determine the survival of *Arachis* germplasm.

Drought tolerance

Some aspects of drought tolerance and avoidance have been presented and discussed by Pizarro and Rincón (1993). Doubt about drought tolerance capacity of *A. pintoi* in association with grasses in the higher areas of the landscape in the Cerrado ecosystem was until recently questionable. However, after four years of research on *A. pintoi* and *A. glabrata* accessions, results are encouraging. In *A. pintoi* (BRA 31143) the green DM percentage ranged from 15 to 38% at the end of the second dry period. This accession also had a high proportion of roots at 58% with a

total root DM yield of 17 t/ha. Sixty percent of the root biomass was in the top 30 cm while 1% was at 1.95 m in depth. This agronomic attribute might help in the efficient absorption and utilization of water and nutrients under stress conditions. Deep root systems have also been detected in drought tolerant rice cultivars under upland conditions (IRRI, 1976). Also, studies with *A. hypogaea* have demonstrated that, under water stress, the roots reach a greater depth compared to non-stressed peanut roots (Lin et al. 1963, Lenka and Misra 1973, Narasimham et al. 1977). Evaluation of seven *A. pintoi* accessions and one *A. glabrata* accession during dry season have confirmed the above observations.

Another favorable plant survival attribute of *A. pintoi* under severe conditions is the rapid soil seed-bank produced. For example, the recovered pure seed yield at 15 months after planting in a red-yellow latosol with 65% clay content, ranged from 50 to 600 kg/ha (BRA 31143). In the same trial, the accumulated DM yield (rainy + dry season) ranged from 0.5 to 4.4 t/ha.

Seed production

Previous information has confirmed that *A. pintoi* cv. Amarillo is a prolific seed producer (Grof 1985a, Cook and Franklin 1988, Diulgheroff et al. 1990, Argel and Pizarro 1992, Ferguson et al. 1992, Ferguson 1993, Pizarro and Rincón 1993, Pizarro et al. 1993). Recently collected germplasm under evaluation not only confirmed the above observations but also showed a significant difference in seed production between accessions of *A. pintoi* and *A. repens* (Table 3). *Arachis repens* is generally vegetatively propagated due to a lack of seed production (Valls and Simpson 1993, Pizarro et al. 1993). Although seed harvesting is relatively easy, timing of seed harvesting is difficult due to the sward growth habit and asynchronous seed set. Information on crop management is

needed, especially on the effect of cutting and/or grazing on seed yield. The effects of defoliation on seed production are well know. The intensity of this effect depends upon the amount, frequency of removal, and the period in the growing season in which removal takes place (Finnel 1929, Aldrich 1959, Sprague 1954, Bolland 1987, Jones and Carter 1989). Preliminary data on the subject suggests that drastic defoliation between three and six months after planting greatly reduces seed production compared to cutting after peak flowering (700 vs. 130 kg/ha).

Potential contribution of *A. pintoi* as a ground cover

This topic is well covered by Cruz et al. (1993). Several experiments have shown that *A. pintoi* is a multiple-use ground cover crop with a high potential to contribute to sustainable agricultural systems. Compared to traditional cover species such as *Centrosema pubescens* Bentham and *Pueraria phaseoloides* (Roxb.) Bentham, *A. pintoi* has the advantage of a nontwining habit with a substantial reduction in maintenance costs. With approximately 6500 ha planted, mainly in the USA, Australia, Colombia and Costa Rica, the potential as a ground cover over the tropical world exist (i.e., $10,000^3$ ha for coconut plantation in Asia, $4,000^3$ ha for coffee and citriculture in Brazil and $2,000^3$ ha for coffee plantation in Colombia). The main agronomic characteristics for uses as a ground cover are wide adaption range, persistence, easy vegetative establishment, good spread, shade tolerance and the choice of seeding or nonseeding varieties.

Animal production

Annual live weight gains of steers grazing pastures of *A. pintoi* have ranged from 160 to 200 kg/hd and from 250 to 600 kg/ha. The effect on milk production has been measured in Costa Rica. In association with *Cynodon nlemfuensis* Vanderyst, milk production increased 17% over that of the grass alone fertilized with nitrogen (van Heurck 1990). Excellent animal production grazed on *A. pintoi* has been obtained in tropical areas without dry-season stress, in areas with 3 to

4 months of dry-stress (i.e., LLanos of Colombia, Lascano 1993), and in the seasonally flooded lands of the Brazilian Cerrado (Table 4).

Agronomic Characteristics: *Arachis glabrata*

Arachis glabrata is a long-lived rhizoma peanut. It was introduced into Florida, USA in 1936 by F. H. Hull from Brazil. Although widely distributed in the states of Mato Grosso and Mato Grosso do Sul in Brazil and more than 300 accessions available (Valls and Simpson 1993), few accessions of the section *Rhizomatosae* have been considered for their potential forage use in the USA. A recent review published by French et al. (1993) discussed the current status both as a forage and as a ground cover crop. Only a brief summary of the more relevant data on cv. Florigraze will be presented. The superior persistence and longevity of this cultivar is mainly due to the superior insect resistance and low susceptibility to diseases (French et al. 1993). The DM yield of this cultivar ranged from 3 to 16 t/ha (Canudas et al. 1989, Prine and French 1992). The effect of fertilization on DM yield is limited and contradictory (Prine 1964, Blickensderfer et al. 1964, French et al. 1993). Other agronomic practices which affect DM yield were clipping height and frequency (Breman 1980, Beltranena et al. 1981, Van Horn and Romero 1986, Ocumpaugh 1990).

Establishment

In general, stand establishment of *A. pintoi*, *A. repens* and *A. glabrata* range from very slow to slow (Prine 1973, French et al. 1993, Argel 1993). As was shown earlier, there were significant differences in the rate of ground cover in new germplasm of *A. pintoi*, *A. repens* and *A. glabrata*. Recent collecting trips have shown that germplasm exist with greater variation in the rate of ground cover spread, variability in seed production and in the leaf to stem ratio. Collecting trips should

be concentrated on plants with those attributes.

Animal performance

The advantage of forage *Arachis* pastures when associated with a grass compared to grass-alone on animal production has been clearly demonstrated (French et al. 1993, Lascano 1993). Individual animal live weight gains in pastures based on *A. glabrata* cv. Florigraze have been high. Sollenberger et al. (1987) reported nearly 1 kg/hd/d in two grazing seasons for steers on Florigraze pastures. In Brooksville, Florida, animal live weight gain during the grazing season ranged from 700 to 900 g/hd/d in a mixture of *Cynodon* and *Paspalum* spp. with rhizoma peanut cv. Florigraze (Williams et al. 1989). Results from the United States are encouraging and have shown the potential use of rhizoma peanuts for hay and silage for dairy cattle, gestating sows, meat goats, horses and poultry (French et al. 1993).

PASPALUM SPECIES

Agronomic Characteristics and Potential Use in Tropical America

Paspalum is a predominant American genus. It contains approximately 330 species, most of which are good for grazing. Several accessions are adapted to wet sites (Anderson 1974) with very low incidence of spittlebug. This last characteristic being the major limiting factor of exotic species, such as *B. decumbens* and *Brachiaria humidicola* (Rendle) Schweick. Preliminary work has shown the potential of the genus *Paspalum* on seasonally flooded lands with high water tables (Grof et al. 1989a). Lands like those constitute a significant portion of the Cerrado ecosystem (12 x 10^6 ha, Goedert 1986).

Forty-two native *Paspalum* accessions were evaluated in an attempt to test their agronomic potential in the Cerrado ecosystem (Valls et al. 1993). A small plot clipping trial was carried out for two consecutive years on a red-yellow latosol (pH 5.9, 62% Al. Sat., and 3% OM). The DM yield in the first 10 months after establishment,

ranged from 350 to 4500 kg/ha. The first regrowth (47 days from the start of the rainy season, 162 mm accumulated rainfall) ranged from 400 to 4000 kg/ha. Maximum growth rates of 324 and 732 kg/DM/ha/wk for *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf (CIAT 664) and *Andropogon gayanus* Kunth (CIAT 621) have been reported for the savanna ecosystem, respectively. In this experiment the accession BRA 12939 produced an intermediate value with a weekly DM yield of 533 kg/ha during the first regrowth.

The mean DM yield accumulated during two rainy seasons (October-May) ranged from 0.5 to 21 t/ha. (Table 5). In seasonally flooded land in the Cerrado ecosystem, total annual DM yield ranged from 2 to 29 t/ha (Grof et al. 1989a). Mean DM yield accumulated during the dry season (May-October) for the 29 surviving accessions and ranged from 20 to 1500 kg/ha. (Table 5). Only two accessions, BRA 12874 and BRA 9610, reached more than 1.0 t DM/ha., with 30 and 34% of green leaf-stem material retention, respectively. The green leaf content at the end of the second dry season (282 mm accumulated rainfall) ranged from 0 to 63%. The highest leaf retention during the dry season was 63% for *Paspalum* spp. (BRA 10154).

Seed yields were variable (0 - 1500 kg/ha of pure seed) and related to the flowering cycle. The early flowering type reached a pure seed yield of 113 ± 115 kg/ha, the intermediate group 420 ± 568 kg/ha and the late flowering type 844 ± 588 kg/ha. Similar high yields have been reported by Grof et al. 1989a (214 to 918 kg/ha pure seed yield). Although pure seed yield were variable in the evaluated collection, they were higher than those reported by Grof et al. 1989b for *Brachiaria* spp. (4 to 155 kg/ha) and for *Paspalum plicatulum* Michx. cv. Rodd's Bay (61 to 360 pure seed yield with 0 to 400 kg N/ha, respectively; Cameron and Humphreys 1976). Although the work is still under way, the

preliminary evaluation support the evidence that the *Paspalum* accessions have high relatively constant seed yield and better synchronization of flowering than many tropical pastures grasses evaluated in the area. Similar observations have been made for *P. plicatulum* cv. Rodd's Bay vs. *B. decumbens* cv. Basilisk (Stür and Humphreys 1987).

Due to the encouraging preliminary results, a set of 84 native *Paspalum* accessions (collected by Dr. J. F. M. Valls curator of *Gramineae* at EMBRAPA - CENARGEN) plus important commercial cultivars of other genera and species are under evaluation in a red-yellow latosol in the Brazilian Cerrado. In the first regrowth (45 days from the start of the rainy season, 270 mm accumulated rainfall), a cluster analysis procedure was applied. Three main groups were obtained. The cluster with the highest yield included the commercial cultivars of *A. gayanus* cv. Planaltina, *B. brizantha* cv. Marandú and *Panicum maximum* Jac. cv. Vencedor and four of the 84 *Paspalum* accessions under test *Paspalum* spp. (BRA 9415, 9652, 9687, and 18996). At that time, the mean CP was $9.4 \pm 1.5\%$ and the mean IVDMD $46.0 \pm 7.2\%$ with 34 units of difference between accessions (30% for *Paspalum* spp. BRA 12921 to 64% for *Paspalum guenoarum* Arechav. BRA 3824, *P. plicatulum* BRA 14851, *and Paspalum* spp. BRA 18996). Exotic African grasses in the genus *Brachiaria* had similar values (Vallejos et al. 1989).

Another important characteristic under evaluation in the *Paspalum* accessions is the yield response to increase in fertility. Preliminary data has shown a mean average increase of 250% in DM yield when the fertilizer was increased from the pasture establishment level to the crop establishment level.

Although few agronomic regional evaluations have been carried out with the genus *Paspalum*, the data from seasonally flooded land and in the well drained savannas of the Cerrado ecosystem are very interesting. Some outstanding attributes mentioned before, such as good seed yield, similar nutritive value to the exotic commercial

grasses, the facility for eradication, the high resistance to the spittlebug, and the high DM yield obtained in seasonally flooded situations call for more attention and evaluation of this American genus in the Cerrado and in the Humid Tropics of Tropical America.

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Table 1. Agronomic performance of a wild population of *Arachis pintoi* (BRA 15121) and *Hyparrhenia rufa* in the State of Goiás, Brazil

Characteristic	Rainy season	Dry season	Regrowth[1]
Total dry matter yield, t/ha	9.5	1.4	1.0
Botanical composition, %			
A. pintoi	13	13	14
H. rufa	83	84	76
Others species	4	3	10
Nutritive value, %			
A. pintoi			
IVDMD	70	-	-
CP	22	-	-
H. rufa			
IVDMD	54	-	-
CP	8	-	-
Seed Yield, kg/ha		330	

[1]88 days in the rainy season

Table 2. Number and daily elongation of primary and secondary stems of three *Arachis pintoi* accessions at 148 days after planting with vegetative material[1]

Characteristic	BRA 31143	BRA 13251	BRA 15121
Diameter, m	2.7	2.3	1.5
Primary stem			
No./plant	20	14	15
Mean length, cm	89	75	48
Mean daily growth, mm	6	5	3
Secondary stems			
No./plant	149	74	40
Mean length, cm	25	16	13
Mean daily growth, mm	2	1	1

[1]Mean of four plants, planted on 9 November 1993, accumulated rainfall = 797 mm, Pizarro and Carvalho, unpublished data.

Table 3. Recovered pure seed yield (kg/ha, mean ± SD) and range in seed yield of forage *Arachis* accessions grown in association with *Paspalum atratum* (BRA 9610) on seasonally flooded land in the Brazilian Cerrado 15 months after establishment

Species	N[1]	Seed yield (mean)	Seed yield (range)
A. pintoi	37	1000 ± 763	0 - 4000
A. repens	9	90 ± 120	0 - 370

[1]Number of accessions studied.

Table 4. Annual live weight gain of steers grazing *Arachis pintoi* (BRA 31143) and *Paspalum atratum* (BRA 9610) pasture on seasonally flooded land of the Cerrado, Planaltina, Brasil (A. Barcellos et al., unpublished data)

Parameter	1992/93	1993/94	1994/95
Stocking rate, AU/ha	2.89	2.63	2.71
Dry Season, g/hd/d	205	211	-
Wet Season, g/hd/d	305	710	762
Total LWG, kg/ha	534	723	525

Table 5. Mean DM yield of 42 accessions in the Cerrado ecosystem of a collection of *Paspalum* spp. aff. *P. plicatulum* (two years of data)

Evaluation period	Accumulated rainfall, mm	Range in DM t/ha
Establishment	775	0.30 - 4.5
Regrowth, 47 days	162	0.40 - 4.0
Wet Season	1384	0.50 - 21.0
Dry Season	288	0.02 - 1.5

VARIABILITY IN THE GENUS *ARACHIS* AND POTENTIAL FORAGE USES

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ABSTRACT

Arachis is a distinctive genus of the Leguminosae with unique reproductive features. Although the cultivated peanut has been used for forage, most forage research has been conducted on perennial species of sections *Rhizomatosae* (*Arachis glabrata* Bentham) and *Caulorrhizae* (*Arachis pintoi* Karp. et Greg., *Arachis repens* Handro). In addition, some members of the section *Procumbentes* have shown acceptable forage quality, flood tolerance, and seed production. One member, *Arachis kretschmeri* Krap. et Greg. (known as the 'Pantanal' peanut), has been recommended for commercial cultivation. A perennial species of section *Triseminatae*, occurring in the semi-arid Brazilian Northeast, has attracted the attention of agronomists. Fast-growing annual species of the sections *Arachis* and *Heteranthae* may be good alternatives for short-rotation systems, hay production, or pioneer plant establishment in pastures. Recent experiments indicated that annual and perennial species of sections *Procumbentes* and *Arachis* may produce enough seed for self-regeneration under grazing conditions. Interspecific and intersectional hybrids, when capable of vegetative propagation, may have potential for use in pastures, as machinery and technologies for cultivation of perennial species are further developed. An extended array of *Arachis* germplasm is now available for forage research.

TAXONOMY

Arachis is a unique genus amongst the Leguminosae due to underground fruits that originate from aerial flowers with a tubular hypanthium (Smith 1950), distinctive anther types in the same flower, and a delicate seed tegument. It comprises many economically important species that are naturally confined to Brazil (over 60 wild species), Bolivia (over 15), Paraguay (12), Argentine (6) and Uruguay (2). About 75% of the probable 80 species are endemic to one of the above countries (Valls and Simpson 1994).

Soon after the discovery of the New World, the common groundnut or peanut, *Arachis hypogaea* L., was utilized as a new crop species in the Old World. The species was validly named by Linnaeus (1753). After a century, Bentham (1841) added new species to the genus. Such species, *A. glabrata*, was recognized, another century later (Otero 1941), as a good forage plant. A second species with potential forage use, *A. repens*, was described by Handro (1958). The third of the most promising forage species, *A. pintoi*, originally collected in 1954, was validly described by Krapovickas and Gregory (1994).

The taxonomy of *Arachis* was in a state of flux for nearly 150 years. A few new species were added to the genus due to confusion over the application of valid species names, the frequent use of names without formal Latin descriptions, and widespread listing of germplasm accessions of unclassified species by collection number. This ended when a comprehensive treatment of the genus was published by Krapovickas and Gregory (1994). Their monograph provided accurate morphological circumscriptions and phytogeographic data, a solid subgeneric framework, and keys to discriminate species. Furthermore, it provided valid names for many new species, some of which are already widely distributed among forage specialists. The present taxonomic structure of the genus encompasses 69 species distributed among nine sections. One of the sections includes two series. A few additional species, unveiled by recent collection work, still remain undescribed. The new species will possibly raise the total number of species to 80 (Valls and Simpson 1994), however, they will unlikely produce any important forage plants.

Variation in pod and seed characters is visibly recognized in *Arachis hypogaea* (Simpson et al.

1992); however, variation in underground structures and in aerial vegetative features is less noticeable. Wild species, on the contrary, are more variable among all plant parts. Association of morphological and reproductive characters, as well as cytogenetic and crossing relationships (Gregory and Gregory 1979), determined the taxonomic grouping of species in sections and series (Krapovickas and Gregory 1994). Axonomorphic to tuberous roots, presence or absence of stolons or rhizomes, vertical to horizontal peg position as the ovary is pushed into the soil, and details of flower morphology, such as distinct standard markings, are important characters for the assignment of species to sections (Gregory et al.1973, Krapovickas 1973, Stalker 1985, Krapovickas and Gregory 1994).

Contrary to the common peanut, most species, comprising seven of the nine sections, are perennial. Section *Arachis* includes both annual and perennial species, while those in the *Heteranthae* are exclusively annuals. The typical self-pollination of *A. hypogaea* may not be the prevailing model for many species. In fact, frequent cross-pollination by bees in nature and in field plots, and even self-incompatibility mechanisms (Simpson et al. 1994) are relevant aspects to consider in the maintenance and breeding of the best forage species.

IMPACT OF RECENT COLLECTION AND EVALUATION

Since 1981, intensified collection of *Arachis* germplasm, especially in Brazil, has lead to a substantial increase in the number of available accessions of both cultivated and wild species. This also resulted in expansion of the known distribution of many species and sections, and the number of species increased in most sections (Valls 1992). Knowledge on sections *Arachis*, *Heteranthae*, and *Extranervosae* was strongly affected by the new findings. The extensive collection of the newly recognized section *Procumbentes*, which was scarcely represented before, unveiled the strong difference between this group and the typical *Erectoides*.

Subsequent characterization and evaluation of newly acquired germplasm has improved the botanical knowledge and stressed additional possibilities of agronomic use for the genetic improvement of the common peanut. Intensive cooperative efforts to characterize and evaluate wild *Arachis* germplasm are underway in many institutions and countries, involving taxonomy, cytogenetics, breeding behavior, genome analysis, wide crosses, resistance to pests and diseases, use as forage, erosion control, gardening, green mulch, and so on.

FORAGE POTENTIAL

Basically, every *Arachis* species produces high quality forage palatable to grazing animals. Crude protein content and *in vitro* organic matter digestibility are generally equal to or better than other commercial tropical forage legumes. However, research emphasis has been placed on accessions with high forage yields, extended seasonal production, persistence under grazing and trampling, competitiveness with aggressive grasses, drought tolerance, flood tolerance, cold tolerance, and diseases and pest resistance.

Most modern research has concentrated on members of sections *Caulorrhizae* and *Rhizomatosae*, or single species, as the Pantanal peanut. Two recent publications, a book edited by Kerridge and Hardy (1994) on the "Biology and Agronomy of Forage *Arachis*" and a chapter authored by Cook and Crosthwaite (1994) on the "Utilization of species of *Arachis* as forage," in a book edited by Smartt (1994) on "The Groundnut Crop," provide a wealth of information on the potential and current commercial use of accessions from sections *Caulorrhizae* and *Rhizomatosae*. An attempt is made here to emphasize the sections and species with greater forage potential, while trying to establish the advantages of exploration of diverse germplasm of *Arachis* for different approaches to forage production.

SECTIONS, SERIES, SPECIES, AND THEIR ATTRIBUTES

Section *Rhizomatosae* Krap. et Greg.

For some time now, researchers have recognized accessions of section *Rhizomatosae* for their potential use as forage (Otero 1941, Prine 1964). Most rhizomatous accessions belong to the typical series *Rhizomatosae*. Although quite variable, as a group, the majority of accessions can be taxonomically included in *A. glabrata*. Some have been classified as *A. hagenbeckii* Harms ex Kuntze, a taxon only accepted by Krapovickas and Gregory (1994) as a variety [(*A. glabrata* var. *hagenbeckii* (Harms ex Kuntze) Hermann]. However, in living collections, most accessions are still identified only to the sectional level. A few other rhizomatous accessions available in genebanks belong to *A. burkartii* Handro of series *Prorhizomatosae* Krap. et Greg. These are generally characterized by low forage production under cultivation, and difficult adaptation to other than natural sites.

Four accessions of *A. glabrata* have been released in the United States: 'Arb' (PI 118457) was originally collected in Brazil; 'Arblick' (PI 262839) and 'Arbrook' (PI 262817) were collected in Paraguay. The most successful was 'Florigraze,' developed at Gainesville, Florida from a volunteer seedling found between field plots of Arb and PI 151982, with intermediate features (Prine 1972, Cook and Crosthwaite 1994). Evaluation of additional materials continues in the United States and Australia with new accessions ready for release as cultivars (French et al. 1994, Cook and Crosthwaite 1994).

As most accessions of this section rarely produce any seed, exchange and increase has been based on vegetative materials. With over three hundred accessions of distinct origins involved, each accession possibly represents a single genotype. Loss of passport data, mislabeling, and invasion of plots by adjacent accessions are common problems in old field collections of *A. glabrata*. Very recently, Maass and Ocampo (1995) used four isozyme systems to successfully fingerprint and distinguish all 15 accessions of *A. glabrata* held at CIAT, Colombia. Broader use of the same and other molecular markers would certainly help monitor genetic integrity in germplasm collections of rhizomatous species of *Arachis*.

Little is known on the breeding behavior of the *Rhizomatosae* and some intriguing questions remain to be answered:

(1) No hybrids have been obtained, thus far, between the diploid *Prorhizomatosae* and the tetraploid *Rhizomatosae* (Gregory and Gregory 1979). It seems that distinct genomes are involved in the tetraploids and diploids (Stalker and Moss 1987). However, most accessions used in such attempted crosses are not good seed producers. Unsuccessful hybridization may be derived from other causes than just genomic or genetic incompatibilities.

(2) Meiotic irregularities have been detected in tetraploid rhizomatous accessions where chromosomes may form up to four quadrivalents (Smartt and Stalker 1982). But, irregular pairing at this level does not necessarily lead to unbalanced gametes, as quadrivalents may have regular segregation.

(3) Pollen germinability in *A. glabrata* seems high enough not to be a relevant obstacle for seed production (Niles and Quesenberry 1992). However, low pollen germination on stigmas has been observed in Florigraze by Niles, who attributed low germination to insufficient stigma moisture (French et al. 1994, Cook and Crosthwaite 1994).

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(4) Stigmas of *A. glabrata* have a very small stigmatic area. This has been considered characteristic of perennial, non-prolific species. Although small, this area is still adequate to lodge at least two viable pollen grains, the same number of ovules in the ovary (Lu *et al.* 1990). Consequently, the reduced stigmatic surface should not constitute a barrier for fertilization.

(5) Scattered populations of *A. glabrata* (and at least one of *Arachis burkartii*) have been found in the wild with relevant amounts of seed. Some also produce small amounts of seed in field plots (Pizarro *et al.* 1993). Cook and Crosthwaite (1994) observed that some accessions fruit freely early in establishment, but seed set decreases rapidly with sward development in spite of profuse flowering. They also report Niles' observation of a high rate of embryo abortion due to competition in dense canopies. At this point, it seems important to mention our own observation, that accessions of section *Caulorrhizae* have considerable variation in this aspect. Some produce high quantities of seed even in very dense swards.

(6) Seedlings found in field plots of *A. glabrata* may develop into plants quite different from those of the parent plot. This, happening in Gainesville, Florida gave rise to Florigraze peanut (Prine et al. 1981). It is not known if Florigraze was a mutant or a segregant seedling autogamously produced by Arb, or if it resulted from cross-pollination between Arb and an adjacent plot, or any other accession kept in the area.

Gregory and Gregory (1979) attempted eleven crosses in a single direction and twelve reciprocal crosses, involving twelve tetraploids of section *Rhizomatosae*. Three reciprocal crosses were fully successful, six succeeded in one direction, and three failed. Of the single crosses, two were successful and nine failed. The weighted average of the cross means of percent pollen stained of the hybrids obtained was 68.% (Gregory and Gregory 1979). Differences in crossability were evident, the most successful parents were GK 10596 (PI 276233, 8 successful crosses out of 10) and GKP 9570 (PI 262817, later released as cv. Arbrook, 6 out of 12), from Paraguay, and GKP 9882 (PI 262286, 4 out of 10) from Brazil (Krapovickas and Gregory 1994). Unfortunately, data on seed production of the same accessions under self-pollination is not available. Gregory's results certainly indicated, at least, a variable degree of cross-compatibility in the tetraploid *Rhizomatosae*. Whether cross-pollination prevails over self-pollination in nature is not yet known.

Further investigation is needed in the reproductive biology of the rhizomatous species of *Arachis*. Further exploration of the available germplasm, and additional collections in nature, may bring to light many interesting genotypes for forage production. On the other hand, a better understanding of the reproductive processes is required to overcome the obvious constraints for peg and seed formation. Subsequent production of new plant types, through crosses involving accessions with distinct advantageous characters, would certainly emphasize the potential of the *Rhizomatosae* as forage crops.

Germplasm collections in the last decade did not significantly affect the known distribution of both rhizomatous series. But there was a steady increase in the number of accessions per species, and a better geographic representation of the total distribution by the new accessions.

Section *Caulorrhizae* Krap. et Greg.

Knowledge of section *Caulorrhizae*, among forage *Arachis* researchers, is generally based on two accessions, each representing a stoloniferous species in the section. The widespread accession *A. repens* (GKP 10538, PI 338274) has always been vegetatively propagated. Most probably, it represents the same genotype in every collection, and sometimes has been duplicated by recurrent

introductions. The original accession of *A. pintoi* (GK 12787, PI 338314, CPI 58113, CIAT 17434, BRA-013251, or cv. Amarillo) has been alternatively exchanged and propagated by seed or cuttings. Although seed propagation may keep some genetic variability in samples, the numbers of individuals exchanged and increased have traditionally been small. When based only on these two accessions, the discrimination between *A. repens* and *A. pintoi* is very easy. The most distinctive characters are the shape and size of the leaflets, the presence or virtual absence of bristles on the petioles and the backs of leaflets.

The forage and ground cover attributes of the above accessions (Akobundu and Okigbo 1984, Grof 1985, Cook et al. 1990, Argel and Pizarro 1992, Cook and Crosthwaite 1994, Kerridge and Hardy 1994), as well as the high levels of resistance in *A. repens* to peanut stripe virus (Herbert and Stalker 1981), and to an insect complex (Stalker and Campbell 1983), determined a high priority for collection and study of the genetic variability of the two species. As the valleys of the rivers Jequitinhonha and Araçuai, São Francisco, and Paranã (a tributary of river Tocantins, in Central Brazil) were thoroughly searched, the available number of accessions increased rapidly. Similarly, the natural distribution of the section was substantially expanded.

When all accessions of *Caulorrhizae* are considered, the morphological features that used to easily distinguish *A. repens* and *A. pintoi* no longer hold (Valls 1992). The two original accessions seem to represent extreme morphological types of a *continuum*, whereas, most accessions show intermediate states or a reticular association of the diagnostic characters. Forage and seed production, as well as disease and pest resistance, also are quite variable among the accessions (Pizarro et al. 1993).

Whenever possible, new collections of *Caulorrhizae* have been extensive and randomized, including cuttings and seeds from many plants of each population. As a consequence, the accessions are significantly variable, however, the traditional increase and distribution, based on a few seeds or cuttings, may restrict the variability available for distinct germplasm users. It may also give rise to genetically distinct subpopulations at each experimental site. Possible loss of genetic integrity of new accessions (Astley 1992) is a considerable threat, when accessions are increased in field plots among many cross-compatible accessions.

Most accessions presently identified as *A. pintoi* produce seed, in the absence of pollinators, under greenhouse conditions. This is a good indication of autogamy. Others will rarely produce seed, even in natural sites. Some accessions, more precisely identified as *A. repens*, will set seed in field plots. But information is lacking on the possible rate of cross-pollination, either in nature or in field plots, where the activity of bees cannot be controlled.

The F_1 hybrid produced in the cross of GK 12787 x GKP 10538 had an estimated pollen viability of 86.8%. This value is much higher than that estimated for crosses involving distinct accessions of a single species in other sections (Gregory and Gregory 1979, Krapovickas and Gregory 1994), and is the result of a cross between extreme morphotypes in section *Caulorrhizae*.

Cook and Crosthwaite (1994) have documented a possible spontaneous hybrid, between the same typical accessions of *A. pintoi* and *A. repens*, found in an experimental plot in Australia. Several off-types, possibly hybrids from bee pollination, have been detected in the forage *Arachis* genebank maintained by EMBRAPA near Brasília, Brazil. They are presently under cytogenetic and molecular investigation. Additional crosses, involving the typical accessions and intermediate types, are

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underway at CENARGEN/EMBRAPA, and may clarify the reproductive and taxonomic structure of what could be better characterized as the *A. repens/A. pintoi* complex. As every controlled hybrid or hybrid produced by bees in the *Caulorrhizae* can be vegetatively propagated and maintained, new genotypes are being produced for further evaluation as forages.

Section *Procumbentes* Krap. et Greg.

Few accessions of section *Procumbentes* have been evaluated for their forage potential. However, the possible advantages of investigating more accessions of this section are emphasized by the good performance of the Pantanal peanut (IRFL 2273, PI 446898; Kretschmer and Wilson 1988). The species has been recently described as *A. kretschmeri* and assigned to this section (Krapovickas and Gregory 1994). Acceptable forage quality, flood tolerance, and seed production are important features shared by several accessions of this species and of *Arachis appressipila* Krap. et Greg. and *Arachis vallsii* Krap. et Greg. Both were collected in the same general area of *A. kretschmeri*, in the municipalities of Miranda and Corumbá, in the Brazilian state of Mato Grosso do Sul. Twelve accessions of these three species are available for evaluation.

The known distribution of this section had a significant northeastern expansion from Bolivia, to near the northern limits of the Brazilian Pantanal. In addition, there was a relevant increase in the number of accessions and species collected in the southern Pantanal. Although plants in this section do not produce true rhizomes or stolons, their prostrate basal branches may be partially covered by mud during floods. Sprouting from buds near the soil surface gives the false impression of rhizomatous growth. Most species of the *Procumbentes* produce horizontal pegs, sometimes very long pegs. In this case, seeds tend to develop near the soil surface. Due to underground seed-harvesting this is a positive agronomic feature.

Section *Triseminatae* Krap. et Greg.

A perennial *Arachis* that forms dense natural pastures in broad floodplains along the river São Francisco, in the state of Bahia, has caught the attention of Brazilian and Australian agronomist (Valls and Simpson 1994). The species is high yielding in poorly drained clay soils throughout the rainy season. It also survives under intensive overgrazing during the long dry season in the Brazilian Northeast. This species produces numerous seed and three-seeded fruits. For some time, it has been wrongly recognized and distributed as *Arachis pusilla* Bentham, and is generally represented in genebanks by two widespread accessions (PI 338448 and PI 338449). Accession PI 338449 is resistant to an insect complex (Stalker and Campbell 1983) and immune to groundnut rust (Subrahmanyam et al. 1985 b).

The single species of section *Triseminatae*, *Arachis triseminata* Krap. et Greg., is more widely distributed than once thought. Its distribution is no longer restricted to the margins and adjacent floodplains of the São Francisco river. The species reaches slightly higher elevations along tributaries of the São Francisco in the states of Minas Gerais and Bahia, from where new germplasm accessions have been collected. With development of adequate machinery and techniques for commercial seed harvest of perennial species of *Arachis* (Cook and Franklin 1988), other prolific seed producing species may attract more attention. This will be especially true for *A. triseminata*, that is well adapted to environments not suitable to the *Caulorrhizae*, *Rhizomatosae* and *Procumbentes*. Nine accessions are presently available for preliminary evaluation.

Section *Arachis*

According to Singh and Singh (1992), *A. hypogaea* is the most important oil seed in the developing world and a valuable source of protein for human and animal nutrition. About 80% of the world production is from

developing countries and approximately 67% from the semi-arid tropics. According to Mangla (1992), two thirds of the world peanut production is crushed to extract edible oil. The residue, called groundnut oil cake, is used as animal and poultry feed, and it ranks among major exports. This meal or cake, reaching up to 45% crude protein, is considered one of the best protein sources for livestock feeding (TAES/OAES 1950).

Groundnut straw, a by-product of manual harvesting and shelling, is well accepted by cattle and is traditionally used by small landholders in subtropical Brazil to feed dairy cows (Araújo 1940). When properly cured, this hay is equal in quality to good alfalfa hay. However, such use of an expensive crop, like peanut, tends to be restricted to lands where alfalfa grows poorly or does not grow at all (TAES/OAES 1950).

Plant diseases reduce the dependable use of peanut plant parts for forage after shelling. Diseases reduce the size of leaves and may require fungicide application, rendering the forage useless for livestock consumption. Disease resistant cultivars may bypass this limitation, adding an extra value to the peanut crop. The use of A. hypogaea for forage production in several regions of the world, and the potential impact of disease resistant cultivars has been recently examined by Cook and Crosthwaite (1994) and Gorbet et al. (1994).

Agronomic and economic constraints limit the direct use of the common peanut as a pasture plant. It's annual life-cycle, lack of dependable reseeding, lack of competitiveness with pasture grasses and weeds, and expensive seed are the reasons most given for its lack of acceptance as a pasture plant (Prine 1964). However, direct use of peanut for forage purposes is an established practice of dairy farms in southern Brazil and Uruguay. Its cultivation is suited for intensive rotation systems that enable land uses an additional three to four months of the year.

Selections of A. hypogaea for forage use are available from a few institutions. Additionally, assorted germplasm accessions, although not specifically evaluated for this purpose, have been originally collected under such usage. Leafier plant types, or plants with very short life cycle, may have their place in integrated agricultural systems.

Similarly, some annual wild species of section Arachis, that produce high forage yields over a short period of time, could be used in rotation systems or for hay production. They may also serve as pioneer plants in the establishment of permanent pastures with slow-growing, perennial forage legumes, such as the stoloniferous or rhizomatous species of Arachis. Beaty et al. (1968), seeded Arachis monticola Krap. et Rigoni in established pastures of 'Pensacola' Bahiagrass and 'Coastal' Bermudagrass, to determine the ability of the groundnut species to establish and persist in the dense sod. They found the Arachis to remain in the sod for at least three years, with perspectives of longer persistence, on the basis of natural reseeding. Once again, such uses will attract high interest, only if improved machinery and technologies for seed harvest of wild Arachis species are further developed. Over 100 accessions of leafy, fast-growing, annual species of section Arachis are available for evaluation. Arachis decora Krap., Greg. et Valls, Arachis duranensis Krap. et Greg., Arachis stenosperma Krap. et Greg. and Arachis valida Krap. et Greg. deserve special attention.

Perennial species of section Arachis may also be as promising as species of Procumbentes. Although seed production is more limited, they share a very similar growth habit (Lu et al. 1990). Recent trials by Kretschmer et al. (1993) indicated that selected annual and perennial species of sections Procumbentes and Arachis may produce enough seed for self-regeneration under grazing conditions. Arachis cardenasii Krap. et Greg., Arachis diogoi Hoehne, and Arachis helodes Martius ex Krap. et Rigoni, may form dense pasture stands in

natural vegetation. *Arachis kuhlmannii* Krap. et Greg., a quite variable species, includes leafy plants that produce high forage yields in natural sites. Some 50 accessions are available of these four species.

The geographic knowledge on the section *Arachis* has been strongly affected by recent germplasm collection work. The eastern limits of continuous natural occurrence of section *Arachis* now reach 47° W. longitude, from 7-20° S. latitude. Very short annual life cycles have allowed some species of this section to escape from the main area, centered in the Brazilian Pantanal, where the perennial species find a suitable environment.

Section *Heteranthae* Krap. et Greg.

Like annual wild species of section *Arachis*, members of section *Heteranthae* may produce high forage yields in a short time period. They should also be tried in rotation systems, or as pioneer crops in the establishment of slow-growing perennial species of *Arachis*. Special emphasis should be given to *Arachis pusilla*, *Arachis dardani* Krap. et Greg., and *Arachis sylvestris* (Chevalier) Chevalier. Once established in the soil, these species produce a rich seed bank in a very short period of time, which will grant periodic coverage of empty spaces in the sward, until the perennial species become completely established.

At first considered geographically isolated from section *Arachis*, represented by a single species (Gregory et al. 1973, under "Pseudaxonomorphae"), section *Heteranthae* is no longer confined to the semi-arid Brazilian Northeast. It encompasses at least four species, with more than 100 accessions available, and overlaps with the area of section *Arachis* in the Brazilian states of Goiás, Maranhão and Tocantins. The highly variable *A. sylvestris* is now represented in germplasm collections by more than 50 accessions, some recognized as resistant to *Didymella arachidicola* (Choch.) Taber, Pettit et Philley (=*Phoma arachdicola* Marasas, Pauer et Boerema) (Subrahmanyam et

al. 1985a) and *Meloidogyne arenaria* (Neal) Chitwood (Nelson et al. 1989). It is the most widely distributed of any wild species in the genus.

Once found and collected, accessions of section *Heteranthae* are prolific and easy to increase. Finding plants in the field at the best time for seed collection is still a critical problem. The short annual life cycle is additionally compressed by the prevailing dry climate of the main area of occurrence of the section. Some species of the *Heteranthae* at first, produce a small number of normal, showy flowers followed by abundant flowers that are reduced in size. These reduced flowers are difficult to see under the foliage and are most probably cleistogamic. When grown at different localities, the proportion of normal to reduced flowers may vary within the same accession.

The intensive collection of members of this section, endemic to Brazil, helped to clarify the taxonomic circumscription of *A. pusilla* and *A. sylvestris*, the first previously assigned to section *Triseminatae* (Gregory et al. 1973). Available information on intersectional cross-compatibility of section *Heteranthae* is restricted to few crosses involving two accessions of a single species of *Heteranthae* (Gregory and Gregory 1979). Further investigation of such genetic attributes throughout the available germplasm of the heterogeneous section *Heteranthae* would seem appropriate.

Sections *Trierectoides* Krap. et Greg. and *Erectoides* Krap. et Greg.

These two sections show restricted distribution and are mostly concentrated in the Brazilian state of Mato Grosso do Sul. A few species reach adjacent areas in the states of São Paulo and Minas Gerais, while others extend to eastern Paraguay. They are quite primitive species with tuberous roots, erect growth habits, long horizontal pegs, and leaves with three or four leaflets, respectively in *Trierectoides* or *Erectoides*. Although able to

produce tall plants in large clumps, most *Erectoides* and the two species of the *Trierectoides*, are slow-growers, probably not very suitable to grazing or trampling. Attention should be kept in section *Erectoides*, due to its high resistance to disease and insect pests (Stalker and Campbell 1983, Subramahnyan et al. 1985b), and confirmed crossability with the three most important sections from the standpoint of forage production, *Caulorrhizae*, *Rhizomatosae*, and *Procumbentes* (Gregory and Gregory 1979).

It seems important to recognized that successful hybridization of plants from section *Erectoides* with desirable attributes, with any good forage species of *Caulorrhizae* or *Rhizomatosae*, may bring to light new attractive plant types. Although most probably sterile, such hybrids may be quite adapted for vegetative propagation, provided the stoloniferous or rhizomatous habit was inherited. As machinery and improved propagation methods for vegetative establishment of *Arachis* species have been developed for *A. glabrata* and *A. pintoi* (Adjei and Prine 1975, Rincón et al. 1992), this may become another line of research of wild *Arachis* species for forage use. In addition, it is interesting to note the very impressive regenerative capacity of one of the members of the *Erectoides*, *Arachis paraguariensis* Chodat et Hassler (Still et al. 1987).

Section *Extranervosae* Krap. et Greg.

This last section is regarded as another of the most primitive in the genus (Gregory and Gregory 1979, Jahnavi and Murti 1985, Stalker et al. 1989). It has species highly adapted to survive in harsh conditions, such as, very dry (without rain for up to six months), low fertility, eroded soils of the Brazilian Cerrados. For the most part, its members are slow-growers, with leathery leaves, variable tuberous root types, and long, horizontal, pegs as in *Arachis marginata* Gardner, or short, inclined, pegs as in *Arachis prostrata* Bentham. In spite of the strong differences between sections

Extranervosae and *Rhizomatosae*, these two species names have been mistakenly used in the literature, with some frequency, to designate accessions of *A. glabrata* and *A. burkartii*.

Species of *Extranervosae* present interesting regenerative attributes, producing good results in tissue culture experiments (Pittman et al. 1984, Johnson and Pittman 1986, Mansur et al. 1993). Pegs of some species often produce adventive roots, that are able to form tubers. Even though separated from the plants, as the pegs collapse after maturation of the fruits, such tubers are able to produce branches from apical buds, thus regenerating new plants.

Section *Extranervosae* had a constant increase in the number of species and accessions as lower latitudes in Central Brazil were explored. Attributes for possible use in breeding, such as the ability to grow in shallow rocky soils or in dry, loose sand, and other adaptive features, are available in more than 100 germplasm accessions. Seed increase and maintenance *ex situ* of live plants of this section is usually difficult, due to very specific soil requirements for survival and seed production. Some species, like *A. marginata*, produce very few fruits per year, even in their natural sites.

Another member of section *Extranervosae*, *Arachis villosulicarpa* Hoehne, is a cultigen, found only in the Nambiquara and Minky Indian settlements in western Mato Grosso State, in Brazil. Distinct accessions of the species produce the largest plants in this section with a notable amount of forage. They grow faster than their closest wild relatives and could be tried for forage production.

FINAL COMMENTS

In the last few decades, the intensive search for genes to improve the common peanut has determined special priority in collection and conservation of new germplasm, including the associated wild *Arachis* species. This effort brought to light a wealth of valuable materials, some with excellent potential for forage use,

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especially in *A. glabrata, A. repens, A. pintoi,* and *A. kretschmeri*. Others may follow and better accessions may be found in those species already under cultivation. Breeding of such species may produce even more successful cultivars.

The impact of adoption of *Arachis* materials in new environments in the tropics has resulted from evaluation of a very small number of accessions and stresses the need for more dedication to this investigation. Intensified collection in Brazil has significantly raised the number of available accessions and species with recognized potential for forage use. New species with such potential are available, but need appropriate evaluation.

Breeding *Arachis* species for forage use will require additional research on floral biology, pollination, and seed set, as distinct breeding strategies may be present. Interspecific and intersectional hybridization may produce interesting new plant types. Even sterile, hybrids inheriting rhizomes or stolons will be suitable for clonal propagation.

Leafy, fast-growing annual species of sections *Arachis* and *Heteranthae* may also become important, under new strategies for forage production. One suggestion is their use as pioneer plants in seed mixtures for the establishment of permanent pastures based on perennial species. This takes advantage of their earliness and ability to produce a rich underground seed bank, in a short period of time, besides the excellent quality forage they provide.

Most of the research on species of *Arachis* with potential for forage use is collaborative, involving several institutions and countries. International cooperation has provided the base for commercial adoption of a growing number of species, and an explosive increase in the amount of scientific information on the subject. This is very well illustrated by the number of relevant publications on wild *Arachis* that came to light in 1994. This cooperative effort should be continued and expanded, covering more species and accessions. It should also cover more specific aspects of the characterization, evaluation, and enhancement of the available germplasm of *Arachis*, for more profitable exploration of this valuable natural resource.

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GRASS-LEGUME INTERACTIONS AS AFFECTED BY DIVERSE TROPICAL LEGUME GERMPLASM IN THE USA GULF COAST STATES

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ABSTRACT

Existing collections of tropical legumes with potential as forage plants include more than 50,000 accessions. Although most tropical legumes are sensitive to frost and unable to survive in cold climates, germplasm with limited cold tolerance has been identified. For subtropical locations, such as peninsular Florida, the adapted germplasm includes wide diversity in potential productivity, forage quality, growth form, propagation, dispersal, and other characteristics. This wide diversity has facilitated the discernment of some relationships among grasses, diverse legumes, and grazing livestock. Some of the characteristics of productive legumes, such as upright growth or viney climbing growth, which enhance competitiveness of the legumes for light also may predispose them to excessive grazing in mixed stands. Competitiveness of legumes with dense grass stands, tolerance of grazing, and aggressive propagation appear to be more critical to commercial success of tropical pasture legumes in the humid southeastern USA than are the more commonly evaluated herbage yield and forage quality characteristics. The limited resources available for germplasm evaluations and the tremendous potential of useful tropical pasture legumes indicate that the primary limiting factors should be the initial basis for efficient evaluation. Thus, after determination of climatic and edaphic adaptation, assessments of suitability of the plant growth form and reproductive capability for survival of grass competition and grazing defoliation should allow elimination of considerable unacceptable germplasm. Remaining materials should then be evaluated for survival of pasture conditions including grass competition and grazing defoliation as early in the evaluation process as seed supplies allow. Yield potential must be considered as a secondary factor since a small proportion of legume in the pasture herbage can produce a measurable production response and stands of many previously identified, high-yielding tropical legumes have proven to be unsustainable under commercial pasture use.

INTRODUCTION

While considerable diversity in plant morphology and other growth characteristics of grasses is apparent, grass pastures in the humid southeastern USA have many common characteristics. Where soil fertility or excessive grazing are not extreme limitations, a dense ground cover and closed canopy are typical. The ground cover and vegetative canopy are often not a pure stand of the planted grass variety. The climate provides potential for forest throughout the region, and ecological processes continually drive the plant community from grassland toward woodland and forest conditions. Grazing management, mechanical treatments of plowing and mowing, and applications of plant nutrients and herbicides are used to interrupt the natural successional processes, thus maintaining the grassland plant community and its productivity. Addition of legumes to these pastures considerably complicates the management required to maintain the grassland community. The tremendous diversity of growth forms among tropical legumes provides both complexity and potential opportunities for developing sustainable grass-legume pastures in the region.

More than 50,000 tropical legume accessions are listed in the major forage legume germplasm collections. This extensive resource includes tremendous diversity. Plant growth form extends from prostrate,

spreading types to trees with herbs, shrubs, and vines also included among the genotypes in the tropical legume collections. Potential herbage production of such diverse plant types ranges from very minimal amounts by some ephemeral species to amounts comparable to productive temperate forage legumes. Plant dispersal and colonization range from such diverse mechanisms as seed with appendages for attachment of pods onto passing animals to vegetative spread of some genotypes by stolons or rhizomes with very limited production of even underground seed. Upon drying, pods of some species open and twist with such force that seed can be thrown several meters. Forage quality differences among species and genotypes are created by a number of factors. Differences in nutritive value often reflect differing protein levels and extents of digestibility, as is characteristic of the major pasture grasses. In addition, many legumes accumulate secondary metabolic products, especially in response to stress factors. Such secondary metabolic products as tannins and alkaloids limit the forage value of various tropical legumes. Acceptability of the herbage to grazing animals, potential intake levels, and selective grazing of mixed swards are greatly affected by such secondary metabolic products. Other plant traits which differ within the germplasm also affect herbage acceptability, intake, and selective grazing. These include characteristics such as woodiness, leaf pubescence, and balance of chemical elements in legume herbage grown on highly infertile and especially extremely acid tropical soils. Along with the differences among genotypes in growth form, dispersal, productivity, and forage quality, differences in environmental adaptation among genotypes provide germplasm suited to a great diversity of environments including those of the subtropical and warm, temperate climates of the lower Gulf Coast States of the southeastern USA.

LEGUME SURVIVAL IN PASTURES

While the range in climatic adaptation among tropical legumes provides opportunities for use of some genotypes for pastures in the lower South, the climate greatly reduces the number of potentially useful accessions. Frost sensitivity of most tropical species prevents winter survival of many otherwise perennial species. Short-day photoperiod responses of many genotypes delay flowering too late in the autumn for seed maturation before frost. Edaphic specificity of other genotypes limit their potential in the region with soil fertility, pH, soil texture, and moisture retention often critical to survival of individual legume genotypes. Almost indiscernible differences in elevation on poorly drained sites often greatly impact survival of marginally adapted genotypes.

Of the genotypes adapted to the climate and soils of specific sites in the region, the dense growth typical of humid-region pastures often provides excessive competition. Some characteristics which appear to enhance survival and competitiveness of various legumes with dense grass swards in the region include perennial growth, ability to compete for light, high reproductive capacity, seed germination at low temperatures, and maintenance of soil seed banks. Dense growth of perennial grasses in the spring provides little opportunity for establishment of slow-growing seedlings. However, the more cold-tolerant, perennial legumes can initiate growth early enough to compete with the grasses in early spring. Some perennial accessions of the genera *Alysicarpus, Arachis, Desmodium,* and *Desmanthus* express various levels of cold tolerance. Species which can germinate at low temperatures can become established before excessive, rapid grass growth begins in spring. Such early germination has been observed in the woody legume *Albizia julibrissin* Durazzini. Either means of early growth initiation, perennation or low-temperature germination, must be combined

with a growth form that provides ability to compete for light. Tropical legumes with viney climbing growth, such as that of Siratro [*Macroptilium atropurpureum* (DC) Urb.], can compete effectively with most grasses for light. Vigorous upright growth, sometimes even initially as etiolated growth, allows some tropical legumes to maintain leaves in the upper grass canopy. High reproductive capacity can be expressed through either vegetative or seed propagation. Vegetative reproduction of some species allows sparse stands of legumes to spread into dense grass swards. *Vigna adenantha* (G. Meyer) Marechal et al. produces dense viney growth which can grow over the grass canopy and smother the grass in an ungrazed pasture. The vines or runners of this legume can root at the nodes, thus expanding the area of coverage by several square meters during a growing season. In contrast, individual plants of *Vigna parkeri* Bak. may spread a distance of only a fraction of a meter each season but still aggressively colonize the area through rooting of short stolons. Species such as *Aeschynomene americana* L., which produce large amounts of seed, can exploit disturbed areas and other gaps in the grass sward with several flushes of seedlings each spring and early summer. Both high levels of seed production and maintenance of soil seed banks contribute to effective establishment of plants from seed and maintenance of populations in dense grass swards. Management to reduce grass competition in spring and early summer through burning, grazing, or mechanical means can greatly increase stands of some legume species from existing soil seed banks. However, some tropical legumes are not tolerant of burning, while responses to burning relative to those of associated grasses may depend on factors such as soil moisture and intensity of the fire (Pitman and Adjei 1994).

Many tropical legumes, which are adapted to the climate and soils of an area and even possess the necessary adaptations to compete effectively with a dense grass sward, fail to survive in pastures. One example in south Florida is Siratro. The viney growth of Siratro makes most leaves accessible to grazing defoliation. Careful stocking involving rotation, appropriate stocking rates, and seasonal deferment can allow effective use of this legume in peninsular Florida (Kretschmer 1972). However, all of the numerous plantings of this legume in Florida during the 1970's eventually failed primarily due to overgrazing. Overgrazing of readily accessible legumes in mixtures with grasses can be considerably moderated by relative palatability of the species involved. In some situations, low legume palatability can substantially enhance legume persistence but still result in at least seasonal utilization by grazing livestock. Some additional plant characteristics which enhance the ability to survive grazing include development of plant crowns, rhizome and stolon development, prostrate growth, and below-ground energy storage. Plant crowns can serve as sources of both energy and buds for regrowth following repeated extensive defoliation. Such morphological development is sometimes expressed by *Desmanthus virgatus* (L.) Willd. Rhizome and stolon production and prostrate growth in some species both enhance survival of grazing and are stimulated by grazing. Some accessions of both *Desmodium heterocarpon* (L.) DC and *Vigna parkeri*, which grow upright in dense grass swards, express phenotypic plasticity by producing low spreading growth under heavy grazing pressure. Energy storage may not be a factor in regrowth of many partially defoliated tropical plant species under favorable growing conditions. However, with repeated heavy defoliation, especially when followed by a dormant period due to either low temperatures or drought, energy available for regrowth can be critical. Some tropical legume species have adaptations for storage of large amounts of energy in extensive below-ground structures. This adaptation has been

called xylopodia (Schultze-Kraft and Giacometti 1979). Development of excessive storage organs, of course, results in reduced herbage growth as photosynthate is partitioned from shoots and leaves.

Some of the more productive tropical legumes exhibit growth characteristics consistent with adaptations for survival in dense grass swards but in contrast with adaptations favoring tolerance of grazing. Many productive tropical legumes produce upright or viney growth. Regrowth from elevated buds rather than from plant crowns is common in some productive species. A large proportion of the more productive herbaceous species are either annuals or short-lived perennials. Thus both tolerance of grazing and potential life span of many productive species are quite limited.

Numerous summer-growing legumes occur naturally in the southeastern USA. These legumes generally provide distinct contrasts with the more productive tropical legumes. Low productivity of herbage is characteristic of the native species, and this is often at least partially due to partitioning of photosynthates to development of extensive below-ground structures. Many of the native legumes are resistant to grazing in contrast to tolerant of grazing. Such grazing resistance is associated with production of anti-quality components and plant morphology. Lignin, tannin, alkaloids, and other chemicals reduce acceptability of the herbage to grazing livestock. Woodiness, thorns, dense leaf pubescence, and even ephemeral production of insignificant amounts of herbage are morphological means by which some native species escape defoliation by livestock.

The divergent mechanisms of survival for many highly productive tropical legumes and some less-productive native species illustrate that compatibility of grass and legume can be attained by a number of means. Failure of many tropical legumes to perform acceptably as components of pastures is due to lack of grazing tolerance rather than lack of compatibility with the associated grass. Persistence of some legumes in pastures due to grazing resistance illustrates that simple survival of the legume is not sufficient. The legume component of the pasture may contribute nitrogen and still be of limited value if it is not grazed. While specialized grazing systems can often enhance survival of grazing-susceptible legumes in pastures, legumes with such requirements produce pasture systems which are vulnerable to even short-term mismanagement.

TROPICAL LEGUMES IN THE SOUTHEASTERN USA

A continuing program of tropical legume evaluation for pastures in peninsular Florida has been conducted since the early 1960's. Initial evaluations indicated that several species were adapted to the climate and soils of south Florida (Kretschmer 1964, 1974). Extensive screening of germplasm collections of selected genera and species revealed tremendous diversity of available germplasm (Kretschmer 1977; Kretschmer and Bullock 1980, Kretschmer et al. 1985, Kretschmer et al. 1990). Despite large numbers of genotypes adapted to the climate and soils of peninsular Florida, limited commercial success has been achieved in developing sustainable grass-legume pastures. The annual *Aeschynomene americana* is a high quality forage plants which can re-establish from seed and maintain productive stands for a few years under favorable rainfall patterns and management (Hodges et al. 1982). 'Florida' carpon desmodium (*Desmodium heterocarpon*) is a grazing-tolerant perennial (Kretschmer et al. 1979) which has provided some successful commercial use. Establishment difficulties due to slow seedling development and unpredictable moisture conditions during the establishment period have limited successful use of this legume (Pitman 1986, Pitman and

Kretschmer 1993). Numerous species which showed considerable promise in initial plot evaluations failed to persist as small plantings in grazed pastures dominated by the commercially used grasses (Pitman and Kretschmer 1984, Pitman et al. 1986, Pitman et al. 1988). Individual accessions which persisted under grazing were those capable of both low spreading growth and regrowth from low protected buds. Of these, a low-growing *Alysicarpus vaginalis*, *Desmodium heterocarpon*, and *Vigna parkeri* appear to be compatible with the prevailing pasture management approaches. As with Siratro, appropriate grazing management could possibly allow successful use of the more productive viney *Vigna adenantha* and the upright *Desmanthus virgatus* (Muir and Pitman 1991a). Even the native *Galactia* species appear to require seasonal deferment from grazing for survival (Muir and Pitman 1991a). Management to allow adequate plant vigor or energy reserves for spring regrowth is apparently critical for these species (Muir and Pitman 1991b). Even under appropriate management, productive use of *Desmanthus virgatus* appears to have greater potential for clay mine-spoil sites than on the extensive sandy spodosols (Adjei and Pitman 1993). Response of growing cattle to even small amounts of the tropical legumes in grass pastures (Aiken et al. 1991a, Pitman et al. 1992) and potential for mixtures of the legumes to provide the legume component (Aiken et al. 1991b) have been documented.

Tropical legumes have also been evaluated for forage potential at a number of locations in Louisiana. In many of these evaluations, herbage yield has been the primary response evaluated. Lack of winter survival of many perennial species and superior yield of annual species in the establishment year have characterized responses in these evaluations (Thro and Shock 1987, Thro et al. 1991). Of the perennials, several *Desmodium* species were reported as the most vigorous

(Thro and Shock 1987). Subsequent evaluations have indicated lack of sufficient cold tolerance for most perennial species. Potential for perennation or reseeding has recently been observed with species of *Alysicarpus*, *Arachis*, and *Desmodium* in southeastern Louisiana (Cuomo, personal communication), with stoloniferous *Arachis* accessions demonstrating ability to compete with summer grasses.

On well-drained sites from Florida into Georgia and along the Gulf Coast, rhizoma peanut (*Arachis glabrata* Bentham) is particularly well adapted (Prine et al. 1981, Prine et al. 1986). Due to expense of vegetative establishment, weed control requirements especially during the establishment period, and risk of stand loss from insufficient rain during establishment, stands are often managed for high-quality hay rather than for pasture. Even when grazed, the investment required for establishment of rhizoma peanut stands will likely dictate that high value use such as creep grazing be the objective rather than maintenance of mature cows. While dense rhizome development and low buds for regrowth indicate potential grazing tolerance, somewhat poor competitiveness of developing stands suggest that stand deterioration may be a hazard with excessive grazing of mixed stands.

Other species of the diverse *Arachis* genus are being evaluated at several locations in the region. Several species appear to have good cold tolerance for coastal areas. Several seed-producing species appear promising in south Florida (Kretschmer et al. 1993) but may not possess the cold tolerance of some vegetatively propagated types. Some of the seed-propagated genotypes have established readily in dense grass stands and survived initial grazing evaluations. These genotypes have not demonstrated the potential to spread and colonize from sparse plantings as have some of the stoloniferous types. The

Arachis genus provides cold tolerant genotypes and plant growth forms adapted to grazing. Low growth habit is associated with rhizomes or stolons in several *Arachis* species. Economical propagation, even of seed-producing types, appears to be a greater constraint to many promising genotypes of *Arachis* than their compatibility with grasses.

EVALUATING TROPICAL PASTURE LEGUMES

Persistence of legume stands has been suggested as a critical limitation to more successful use of forage legume technology (Marten et al. 1989). Interactions of grasses and legumes in pastures, especially through plant competition, are undoubtedly major factors. Ecological evaluations of interspecific competition between a selected grass and all available legume species would certainly be excessive, considering available resources. A combination of existing information and preliminary plant screening will allow elimination of many unadapted genotypes and plants with inappropriate growth forms for survival in pastures. Many special uses can be made of legumes with differing attributes. However, when the objective is identification and development of commercially useful pasture legumes, the list of potential candidates can be narrowed rather quickly. For extensive use, it is unlikely that a legume with limited seed production capability can be economically propagated. Lack of sufficient seed production will also limit resilience under such short-term perturbations as drought and the typically concomitant overgrazing. Annual legumes may be superior to available perennial types in sparse grasslands of drier regions with seasonal rainfall, however, most annual legumes cannot establish reliably enough in the dense grass stands of the southeastern USA to form sustainable stands. Other than a few woody species, even the perennial legumes are rather short lived. Thus, sustained stands require seed

production or vegetative propagation. When plant recruitment is dependent upon seed production, plant morphology must not only be appropriate for survival of the established plant under grazing, but it also must facilitate flowering and seed production in spite of grazing defoliation. Persistence of the legume stand will depend upon seedling establishment within the established grass stand. Seedling vigor is then a critical component of even the desirable perennial legume.

Perhaps as important in the search for sustainable pasture legumes as the essential traits is recognition of some desirable characteristics which are not necessarily essential. When formulating a ration for ruminant livestock, one approach is to meet the energy needs as cheaply as possible and supplement as needed to balance other nutrient requirements. In pastures in the southeastern USA, grass is typically cheaper and easier to grow than are legumes. The cost advantage could readily change with the price of nitrogen fertilizer. At this time, however, grass pastures are much more sustainable in the region than are legumes. Legumes can serve as protein supplements and contribute substantially to low-quality grass pastures through the summer, even if they are not the most productive legumes available. Thus, the common emphasis on yield data early in an evaluation program may only provide rankings among unacceptable options. It may even lead to the wrong choices early in a program. The somewhat less-productive, persistent legume may be eliminated based on the secondary response of yield. Selection and breeding efforts with high-yielding, unsustainable legumes may then proceed.

Climatic and edaphic adaptation must be determined initially. Morphology, seed production potential, pest problems, and some other characteristics can be assessed for adapted accessions during preliminary screening. If the plant being evaluated is a

legume intended for use in a mixed grass pasture, yield of the legume in clipped plots may not only be of little, if any, value, but it may misrepresent the ultimate usefulness of the material under evaluation. The hazards of inadequate emphasis on primary objectives, specifically long-term survival, are illustrated by the development of 'Shaw' creeping vigna (*Vigna parkeri*). This legume was deleted from the evaluation process during initial stages in the 1960's because it was not among the higher yielding species (Cook and Jones 1987). By the late 1970's and early 1980's, potential for the legume was recognized because it had persisted and spread from the early plantings, while other entries had disappeared. Thus, it is critical to base initial selections of superior genotypes on the traits which actually determine satisfactory performance. Satisfactory performance of a pasture plant obviously depends upon survival of the plant in a pasture. Based on responses world-wide with tropical legumes, it is unlikely that many genotypes will remain in the evaluation process by the time it is appropriate to select the most productive one. Typically, the case has been that an acceptable entry with a minimum of other limitations has been sought at the end of the evaluation process, regardless of yield ranking. Of course, legumes with insignificant herbage production potential would be recognized and discarded during preliminary evaluation.

In some programs, highly mechanized procedures for laboratory evaluation of plant characteristics allow early, low-cost assessment of many chemical characteristics. The cost and usefulness of such evaluations will determine when they can most effectively be interjected in the evaluation process. The wide diversity in forage quality, including anti-quality components, of tropical legumes may allow elimination of some accessions early in the evaluation program through identification of unacceptable characteristics. Such early chemical evaluation will generally be appropriate only in specific situations. Generally, the legumes will provide sufficient protein levels and increases in passage rate and forage intake to improve forage quality of warm-season grasses throughout the summer. Thus, the appropriate place for efficient, economical assessment of routine forage quality attributes in evaluations of diverse tropical germplasm is late in the evaluation process when the bulk of the unacceptable material has been eliminated.

As resources for research become limiting, efficient use of available resources becomes critical. Approaches for more efficient evaluation of pasture legumes have been suggested for particular objectives (Keoghan 1985, Kretschmer 1989). A tremendous international investment has been made in the collection, storage, seed increase, and partial preliminary evaluation of the existing thousands of tropical legume accessions. These legumes hold potential value for various uses and environments throughout the tropics and subtropics. Efficient and timely evaluation is critical for realization of potential benefits and return on the investment already made. Both continued support to make this germplasm available and appropriate evaluation of the available germplasm are currently critical aspects of the long term international effort to increase productivity and sustainability of grasslands in the tropics and subtropics.

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INTERACTIONS OF THE LESPEDEZAS WITH GRASSES

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ABSTRACT

The lespedezas are warm-season forage legumes which are desirable to grow in mixture with forage grasses. When intercropping, various types of interactions between neighboring plants can arise. Biochemical interplant interaction (through secondary metabolites) is commonly referred as allelopathy. Both the lespedezas and the grasses, when grown in mixtures, produce allelopathic compounds. Some cultivars of some grass species are not affected by sericea lespedeza allelopathic compounds and allelopathic effects of some grass cultivars on sericea lespedeza are large whereas others have no affect. Therefore, selection for improved production under coexistence is possible and success is likely. Strategies for improving coexistence of legumes and grasses should initially be directed toward selection of the legume for better adaptability to already established perennial grass species, thus they can be used in pasture renovation. Future selection of forages should be done concurrently for the grasses and the legumes that will coexist in pastures. Such a mixture will need to outperform the respective pure stands in either dry matter annual distribution, persistence, yield, and/or yield stability.

INTRODUCTION

Grasses are generally the main component of pastures whereas legumes frequently are the minority. The advantages of grass-legume mixtures over monoculture are well documented for forage production and animal performance (Petriz et al. 1980). Inclusion of a legume increases forage yield and quality compared to unfertilized grasses. Although the increment in forage yield may not be as much as when fertilizing with nitrogen, inclusion of the legume may provide farmers with the highest profit (Evers 1989).

Sericea lespedeza [*Lespedeza cuneata* (Dumont) G. Don], Korean lespedeza [*Kummerowia stipulacea* (Maxim.) Makino], and striate lespedeza [*Kummerowia striata* (Thunb.) Schindler] are warm-season forage legumes which are desirable to grow in mixtures with grasses. Mixtures of tall fescue (*Festuca arundinacea* Schreb.), a cool-season plant, and sericea lespedeza, a warm season plant, seem ideal for improving pasture productivity because they have temporal compatibility (different growing seasons), a major factor in promoting coexistence between species competing for renewable resources. However, Hoveland et al. (1975, 1990) reported that pastures of sericea lespedeza-grass mixtures [tall fescue or bahiagrass (*Paspalum notatum* Flugge)] produced about the same amount of dry matter as sericea lespedeza alone unless they were fertilized with nitrogen. Danho (1984) reported a drastic reduction in dry matter production of both sericea lespedeza and tall fescue when grown in a mixture in relation to the respective pure stands, thus, suggesting a negative effect on each other. He also determined that sericea lespedeza contributed to an increase in nitrogen content in tall fescue and bahiagrass. When a cool-season grass such as tall fescue was mixed with sericea lespedeza, forage dry matter annual distribution improved to the point that animal performance was as good as on tall fescue-clover (*Trifolium spp.*) mixtures and bermudagrass [*Cynodon dactylon* (L.) Pers.] pastures (Hoveland et al. 1990). This result agreed with the view of Antonovics (1978) that mixtures have the advantage of better overall stability than pure stands, even if mixtures do not out yield pure stands.

The stand of sericea lespedeza in a 'Serala' sericea lespedeza-'Kentucky 31' tall fescue pasture slightly decreased after three years whereas the stand in a mixture with orchardgrass (*Dactylis glomerata* L.) did not change (Hoveland et al. 1975). Application of nitrogen reduced sericea lespedeza stand. Hoveland et al. (1990) observed a reduction in 'AU Triumph' tall fescue stand mixed with 'Interstate 76' sericea lespedeza under grazing at the end of two years whereas the sericea lespedeza cultivar maintained its stand.

Overseeding a sericea lespedeza pasture with ryegrass (*Lolium multiflorum* Lam.) or rye (*Secale cereale* L.) increased the pasture annual production if nitrogen fertilizer was applied (Hoveland et al. 1990). Ryegrass increased dry matter production of the pasture more than rye. Korean lespedeza and striate lespedeza are commonly double cropped with small grains that are harvested as fodder or grain or overseeded on grass pastures (Henning and Risner 1988). Good animal performance has been reported in cattle grazing annual lespedeza-grasses mixtures (Henning and Risner 1988).

PLANT INTERACTIONS INVOLVING ALLELOPATHY

When intercropping, various types of interactions between neighboring plants can arise. Interactions between plants most commonly occur through an intermediary such as light, water, nutrients, natural enemies, secondary metabolites, or symbionts (Goldberg 1990). Plants produce a wide variety of organic compounds, the so-called secondary metabolites (some of which are phytotoxins), that are beginning to be accepted by the scientific community as major factors in plant protection against a variety of organisms and attractants of animals for pollination and seed dispersal (Wink 1988).

Biochemical interplant interaction (through secondary metabolites) is commonly referred as allelopathy. There are several reviews that discuss the extensive research on allelopathic effects among plants (Rice 1983, Hoagland and Williams 1985, Putnam and Tang 1986). Studies on forage crops have identified a wide variety of allelopathic compounds (Table 1). This type of interaction can have inhibitory or stimulative effects. Most reports on interplant interaction through secondary metabolites show evidence of inhibitory effects. One of the few examples of stimulative effects is the case of triacontanol present in alfalfa shoots which enhanced growth of several plants when chopped alfalfa shoots were placed in the ground (Ries et al. 1977) (Table 1).

Plant residues left on the soil surface may be a major source of allelopathic compounds in the field. Phenolics are the main type of phytotoxic substance obtained from crop residues. The allelopathic compounds most frequently reported in forage crops are acetic, butyric, p-coumaric, and ferulic acids (Table 1).

Decomposition and weathering of plant residues is often coupled with formation of allelopathic substances (Guenzi and McCalla 1966, Guenzi et al. 1967) (Table 1). McCalla and Duley (1949) determined that decomposition of diverse sources of organic nitrogen resulted in allelopathic effects on corn seedlings that varied depending on the source of nitrogen. Their work indicated that allelopathic substances are natural by-products of organic matter decomposition. The investigation of McCalla and Duley (1949) also suggested that allelopathic effects were the result of a combination of phytotoxins from residue decomposition and from microorganisms that grow more profusely in the presence of certain residues. Norstadt and McCalla (1963) identified a large number of isolates that reduced corn germination to 50% or less. Martin et al. (1990) reported that allelopathic effect of

residues increased as their nitrogen content increased. The most severe phytotoxicity occurred in fields where decomposition of residues took place in cold, wet soils (McCalla and Duley 1949, Tousson et al. 1968).

Aging of plant residues reportedly reduces phytotoxicity. Wheat and oat residues had a decreased phytotoxicity to almost nontoxic levels after eight weeks in the field. Maize and sorghum residues required 22 to 28 weeks. Variability in the release of phytotoxic compounds among wheat genotypes has also been measured (Guenzi et al., 1967).

A second source of phytotoxins is root exudates. They are substances released into the surrounding medium by healthy and intact plant roots (Rovira 1969). Root exudates have been implicated in interactions between plants and soil microorganisms (Rovira 1969, D'Arcy Lameta and Jay 1987, Richardson et al. 1988) and plant-plant interactions (Rovira 1969). Research on root exudates has shown that they can reduce seed germination and plant growth (Pope et al. 1985 a and b, Kalburtzi et al. 1989). Hence, root exudates may be of importance in intercropping and crop rotation. Root exudates include a variety of compounds with biological activity some of which are responsible for autoallelopathy in some plants (Rovira 1969). Emanation of volatile compounds and leachates from plant tissue have also been shown to inhibit seed germination, seedling growth, and root growth (Rice 1974).

ALLELOPATHIC EFFECTS OF THE LESPEDEZAS

Sericea Lespedeza Residues

Sericea lespedeza produces a large amount of residues. Pieters et al. (1950) reported that accumulation rates of leaf litter on the soil surface ranged between 1,119 and 4,476 kg/ha/year depending on the way plants were harvested. Kalburtji and Mosjidis (1992a) measured 3,800 kg/ha of residues on a field of sericea lespedeza grown for four years for hay production and 7,600 kg/ha in a field cut once at the end of each summer. Adams (cited by Pieters et al. 1950) measured a maximum accumulation of 31,332 kg/ha of plant residues after eight or nine-year in a field where sericea lespedeza had grown for seed production.

Large amounts of dead leaves and stems that accumulate on the soil surface in sericea lespedeza fields is of much significance for soil conservation because of the consequent improvement in soil physical properties (Fletcher and Livingston 1949). Soils where sericea lespedeza had grown showed a substantial increase in organic matter and nitrogen content. Furthermore, yield of maize and cotton following sericea lespedeza were much higher than those in other rotation schemes (Pieters et al. 1950, Baldridge 1957).

Langdale and Giddens (1967) reported some cases where maize (*Zea mays* L.) following sericea lespedeza presented stunted growth temporarily when planted using minimum tillage. Symptoms disappeared before the plants reached maturity. They determined that the addition of stem residues of sericea lespedeza to the soil reduced maize early growth whereas addition of leaf residues increased maize early growth. Langdale and Giddens (1967) found that several phenolics (Table 1) were produced during decomposition of sericea lespedeza residues when soil moisture content approximated field capacity.

More recently, Kalburtji and Mosjidis (1992a, 1993a) determined that sericea lespedeza residues had small negative effects compared to the positive effect of N fertilization on several cultivars of bermudagrass, bahiagrass, rye, ryegrass, and

tall fescue. Their studies indicated that establishment of rye and tall fescue in a sericea lespedeza field likely requires higher seeding rates than normally used to compensate for reduced germination, whereas ryegrass, bermudagrass, and bahiagrass would not be affected. Kalburtji and Mosjidis (1993a) measured reduced growth and shoot-N levels in rye, ryegrass, and tall fescue when sericea lespedeza residues were incorporated into the soil. Immobilization of N appeared to be the main factor limiting plant growth. Their conclusion agreed with Stowe and Osborn (1980) who reported that toxicity of phenolics depends on the soil nutrient status, particularly N and P levels. They suggested that toxicity of phenolic acids is accentuated on low fertility soils. Bermudagrass and bahiagrass had a similar response to the sericea lespedeza residues and N fertilization (Kalburtji and Mosjidis 1992a). It can be concluded from the work of Kalburtji and Mosjidis (1992a, 1993a) and Hoveland et al. (1975, 1990) that N fertilization will be required to enhance growth of cool- and warm-season grasses which otherwise would be curtailed by sericea lespedeza residues.

Sericea Lespedeza Root Exudates

Kalburtji and Mosjidis (1992b, 1993b) studied the effects of sericea lespedeza root exudates on tall fescue, bermudagrass and bahiagrass. They determined that percentage of emergence of any of the grasses was not affected by root exudates, however, radicle and/or coleoptile lengths were reduced to various degrees in all cultivars of all species except in the AU Triumph tall fescue which was not affected. Above ground biomass of some tall fescue cultivars was reduced but others were not affected. Some bahiagrass cultivars had reduced aboveground biomass whereas others were not affected by root exudates of particular sericea lespedeza cultivars.

Biomass of bermudagrass was not affected by any sericea lespedeza cultivar.

Bieber and Hoveland (1968) determined that sericea lespedeza shoot and root extracts did not affect seed germination of crownvetch or crimson clover. The same extracts reduced radicle length of crownvetch (*Coronilla varia* L.) whereas crimson clover (*Trifolium incarnatum* L.) seedlings were not affected. Logan et al. (1969) reported the existence of a germination inhibitor of its own seeds in the seed coat of sericea lespedeza. To the contrary, Cope (1982) determined that germination and root length of sericea lespedeza were not inhibited by leachates from its own seeds.

Annual Lespedezas

Root exudates of striate lespedeza cv. 'Kobe' did not affect growth of crownvetch. However, residues incorporated into the soil reduced crownvetch dry matter weight but did not affect seed germination (Bieber and Hoveland 1968). Creek and Wade (1985) found several phytotoxins in root exudates of striate lespedeza cv. Kobe (Table 1). Rice (1974) determined in a field study that Korean lespedeza inhibited the nitrifying bacteria *Nitrobacter* and *Nitrosomonas*.

EFFECT OF GRASSES ON SERICEA LESPEDEZA

Seed leachates of annual ryegrass and orchardgrass reduced germination and root length of sericea lespedeza. Leachates from bluegrass caused a small reduction whereas those from tall fescue had no effect on root length (Cope 1982). The effect of seed leachates of different annual ryegrass cultivars on sericea lespedeza germination and root length ranged from no effect to a large reduction in root length. Annual ryegrass inhibitors were located in both seed and glumes. Extracts from the latter caused the larger reductions in germination and root length (Cope, 1982).

COEXISTENCE OF LEGUMES AND GRASSES

The differences in forage yield between pure stand and sericea lespedeza-grass mixtures is a common occurrence in grass-legumes mixtures (Hoveland et al. 1975, 1990; Danho 1984). Collins and Rhodes (1989) demonstrated that large variation exists in the compatibility of white clover and perennial ryegrass populations. Furthermore, Evans et al. (1985) established that the highest biomass yields were obtained when the clover-grass mixture was based on components that had previously grown together, thus, suggesting coevolution among the competitors. Lüscher et al. (1992) confirmed the results of Evans et al. (1985) after eliminating variation carried over from the sampling site (carry-over effect) and when an introduced *Rhizobium* strain was used to avoid the possible effect of natural *Rhizobium* strains as suggested by Chanway et al. (1989). Lüscher et al. (1992) concluded that besides adaptation to the environment, interspecific competitors, and soil microorganisms, there is also adaptation to the neighboring competitor.

Goldberg (1990) argued that interaction among plants consist of two different processes: (1) at least one of the plants involved in the interaction has an effect on the abundance of the intermediary (e.g., resources in the case of competition, allelopathic compounds in the case of allelopathy) and (2) a response to changes in abundance of the intermediary. These processes would be driving forces for selection for coexistence and for coevolution (i.e., a trait in one species evolves in response to a trait in another species, which trait has itself evolved in response to the trait in the first species). The net result of selection for coexistence or of coevolution would be to avoid, minimize or tolerate the interaction.

Antonovics (1978) concluded, after analyzing the population genetics of mixtures, that competitive ability of species in a mixture changes as a result of natural selection, however, this may not necessarily result in an increased agronomic yield. Antonovics (1978) also concluded that there needs to be explicit selection for alternative use of resources (over compensatory effect) as seen in Allard and Adams (1969) work on barley (*Hordeum vulgare* L.). However, Antonovics (1978) warned that selection for interaction in which the mixture yields more than pure stands is possible but a positive response is not certain. Finally, Antonovics (1978) concluded that even if mixtures do not out yield pure stands, they may have better overall stability when facing environmental variations.

Despite the arguments raised against the existence of allelopathy, evidence for allelopathic effects in the field has accumulated (de Wit 1978, Williamson 1990). It is logical to expect that phytotoxins would be one more factor among the many that play a role in coexistence of different species and genotypes.

SELECTION FOR IMPROVED GROWTH IN MIXTURES

Selection in pastures starts at planting time when mortality rates of up to 90% have been measured (Hill 1990). Also, when forage crops are planted in pure stands at high densities there is frequently high mortality (Antonovics 1978). Either type of mortality may be accompanied by elimination of some species, a decrease in variability among the survivors, and a genetic shift (a significant change in gene frequencies between the original population and survivors) (Antonovics 1978, Hill 1990). The nature and magnitude of the genetic changes will depend on the breeding system of the species and on intergenotypic interactions (Allard and Adams 1969). Antonovics (1978) suggested that high density may intensify

selection pressure and, thus, take full advantage of genetic differences.

Traditionally, breeding of forage cultivars is practiced on pure stands, thus, the population is not exposed to the selection pressure of a companion species. Cultivar development for use in mixtures requires that the populations must be exposed to the combined effects of intra- and interspecific competition during the breeding process. Furthermore, the grazing animal should also be included in the selection scheme when the plants are to be grown under grazing conditions. The animal is an essential element of the system that may determine survival or predominance of any of the plant species in the mixture. Hill (1990) proposed a recurrent selection program to improve coexistence between forage species. The first step is to identify traits promoting general ecological combining ability and genotypes that carry them. Second, select and evaluate the genotypes of one or both components in mixture using a diallel or a North Carolina design II arrangement of the mixtures. Third, polycross the selected material and initiate a second cycle of selection. Hill's (1990) program is thorough but long, complex, assumes that traits that confer superiority in mixtures can be easily identified, and does not include the grazing animal.

An alternative reciprocal recurrent selection program for breeding cultivars for mixtures to be used under grazing conditions is to plant a high density mixture of genotypes with desirable agronomic traits of the two species, have them grazed for at least one season, harvest seed of individual plants, test the progenies in mixture with the other species, polycross the selected material and initiate a second cycle of selection. Should the intended use of the cultivars be in ley farming grazing can be substituted by mowing.

In summary, certain cultivars of some grass species are not affected by sericea lespedeza allelopathic compounds and allelopathic effects of some grass cultivars on sericea lespedeza are large whereas others do not affect this legume. Therefore, selection for improved production under coexistence is possible and success is likely. Strategies for improving coexistence of legumes and grasses should initially be directed toward selection of the legume for better adaptability to already established perennial grass species, thus they can be used in pasture renovation. Future selection of forages should be done concurrently for the grasses and the legumes that will coexist in pastures. Such a mixture will need to outperform the respective pure stands in either dry matter annual distribution, persistence, yield, and/or yield stability.

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Table 1. Allelopathic compounds identified in forage crops

Species	Compounds and Source	Authors
Alfalfa (*Medicago sativa* L.)	Medicarpin (3-hydroxy-9-methoxypterocarpan) (leaves extract) Saponins (root extract) Triacontanol (shoot extract)	Dornbos et al. (1990) Miller (1983) Ries et al. (1977)
Bermudagrass [*Cynodon dactylon* (L.) Pers]	p-cumaric, syringic, vanillic, p-hydroxybenzoic, and o-hydroxyphenilacetic acids (leaves extract)	Chou and Young (1975)
Digitgrass (*Digitaria decumbens* Stent.)	Ferulic, syringic, vanallic, and o-hydroxyphenilacetic acids (leaves extract)	Chou and Young (1975)
Guineagrass (*Panicum maximum* Jacq.)	o-hydroxyphenilacetic acid (leaves extract)	Chou and Young (1975)
Johnsongrass [*Sorghum halepense* (L.) Pers.]	Chlorogenic and p-coumaric acids, dhurrin and its break-down products HCN and p-hydroxybenzaldehyde (leaves and rhizome extracts and their decomposition)	Abdul-Wahab and Rice (1967)
Limpograss [*Hemarthria altissima* (Poir.) Stapf. & Hubbard]	3-hydroxyhydrocinnamic, benzoic, phenylacetic, and hydrocinnamic acids (root exudates)	Tang and Young (1982)
Oat (*Avena sativa* L. and other *Avena* species)	Scopoletin and glucose-7-scopoletin (root exudates) p-coumaric acid (residue decomposition)	Fay and Duke (1977) Guenzi and McCalla (1966)
Paragrass [*Brachiaria mutica* (Forsk.) Stapf.]	Vanillic, p-hydroxybenzoic, and o-hydroxyphenylacetic acids (leaves extract)	Chou and Young (1975)
Quackgrass [*Elytrigia repens* (L.) Nevski]	Acetic and butyric acids (root leachates)	Hoagland and Williams (1985)
Red clover	Medicarpin (3-hydroxy-9-methoxypterocarpan)	Higgins and

Table 1. cont.

Species	Compounds and Source	Authors
(*Trifolium repens* L.)	(leaves leachates) Ononin, daidzein, daidzein 7-glucoside, formonetin, genistein, biochanin A, biochanin A 7-glucoside, biochanin A 5-malonate, trifolirhizin (shoot extract)	Smith (1972) Chang et al. (1969)
Rhodesgrass (*Chloris gayana* Kunth.)	Ferulic, p-cumaric, syringic, vanillic, p-hydroxybenzoic, and o-hydroxyphenilacetic acids (leaves extract)	Chou and Young (1975)
Rye (*Secale cereale* L.)	2,4-dihydroxy-1,4(2H)-bezoxazin-3-one and its break-down product 2 (3H) benzoxazolinone (shoot and residue extracts) β-phenyllactic acid and β-hydroxybutiric acid (shoot extract) Acetic, butyric, benzoic, phenylacetic, hydrocynnamic, 4-phenylbutyric and ferulic acids (residue decomposition)	Barnes et al. (1987) Schilling et al. (1985) Patrick (1971)
Sericea lespedeza [*Lespedeza cuneata* (Dumont) G. Don]	Vanillin, ferulic, p-coumaric, and protocatechuic acids (residue decomposition) Soyasapogenol B, soyasapogenol E, genistein (root extracts and root exudates)	Langdale and Giddens (1967) Lynn (1985)
Striate lespedeza *Kummerowia striata* (Thunb.) Schindler	Ferulic, gentisic, and syringic acids (root exudates)	Creek and Wade (1985)
Tall fescue (*Festuca arundinacea* Schreb.)	Lactic, succinic, glyceric, glycolic, shikimic, malic, citric, and quinic acids and other unknown compounds (leaves and root leacheates)	Peters and Luu (1985)
Wheat (*Triticum aestivum* L.)	Ferulic acid (shot extract) Salts of acetic, propionic, and butyric acids (residue decomposition) p-Coumaric acid (residue decomposition)	Schilling et al. (1985) Tang and Waiss (1978) Guenzi and McCalla (1966)

Table 1. cont.

Species	Compounds and Source	Authors
Western wheatgrass [*Pascopyrum smithii* (Rydb.) Love]	Phenolics (residue extracts)	Bokhari (1978)

DISEASE INTERACTIONS IN LEGUME-GRASS SWARDS

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ABSTRACT

Associated grasses alter the frequency and severity of pathogen infection in forage legumes. Incidence of alfalfa mosaic and white clover mosaic virus was lower in white clover (*Trifolium repens* L.) growing with tall fescue (*Festuca arundinacea* Schreb.) than in white clover monoculture. Plant population, crown and root diameter, and incidence and severity of *Fusarium*-induced internal crown breakdown were reduced in arrowleaf clover (*Trifolium vesiculosum* Savi) sown with annual ryegrass (*Lolium multiflorum* Lam.). In root-knot [*Meloidogyne incognita* (Kofoid & White) Chitwood] nematode-infested soils, establishment and productivity of susceptible legumes were improved by the presence of resistant bermudagrass [*Cynodon dactylon* (L.) Pers.] cultivars. In all these cases, the frequency and severity of infection in the legume was reduced due to the unsuitability of the associated grass as a host for the pathogen, a reduction in legume plant density, or alteration of the sward microclimate.

INTRODUCTION

Diseases are one of many factors that stress annual and perennial forage legumes. Forage legume productivity and persistence are also influenced by utilization and fertilization, precipitation and temperature, and other biotic factors such as insect pests. Although these factors may produce stress individually, they often interact with one another to produce a cumulative stress load in a susceptible crop (Leath 1985). For example, fungal leafspot infection of clovers (*Trifolium* spp.) is usually favored by cool, wet weather, while hot, humid conditions during the summer may increase white clover susceptibility to stolon rot. Where grass-legume swards have been managed to permit forage accumulation, the probability of fungal leafspot infection of the legume is greatly increased. Thus, disease incidence in forage legumes is a product of several factors, some of which can be controlled by man and some of which cannot.

Diseases constitute a major problem in forage legumes because the producer desires not only greater productivity and quality but greater persistence of perennial species as well. Perenniality of forage legumes contributes to increasing productivity losses caused by diseases over time because the host crop is always available for infection and often under stress due to management or the environment. However, diseases in general are often tolerated by producers because (1) forages typically are marketed in bulk package, which may mask disease effects; (2) forages and pastures are perceived as having relatively low market value; (3) forages are often utilized on the farm, shielding the crop from true market pressures; (4) losses are not always obvious, particularly when the loss of a mixture component is offset by an increase of another, and; (5) control methods are not always available, effective, economical, or permitted because the treated crop must be consumed by animals (Leath 1983). Thus, the best long-term solution to disease loss in forages is to incorporate host plant resistance into susceptible species.

In the absence of host plant resistance, a forage producer may attempt to manage the crop to reduce disease incidence, however this strategy generally reduces only the rate of disease spread and does not prevent infection. Possible management approaches include: (1) timely utilization (excessive herbage accumulation produces an environment more conducive to disease development); (2) weed control (weeds may serve as alternate hosts of certain pathogens); (3) insect control (some insects serve as vectors of pathogens and may contribute to the cumulative stress load); (4) crop rotation (non-host species interrupt the disease cycle); (5) soil

fertility (potassium generally increases the physical resistance of the host plant to pathogens), and; (6) legume-grass mixtures (grasses alter the sward microclimate, reduce the density of susceptible legume plants, and may reduce frequencies of infection). Utilizing grass-legume mixtures is particularly important for producers desiring to grow annual and perennial clovers because most species lack disease resistance. The following examples describe the effects of various pathogens on clover productivity and persistence and the influence of associated grasses on clover disease incidence.

VIRUS DISEASES IN LEGUME-GRASS SWARDS

Viruses are some of the most prevalent pathogens of annual and perennial clovers in the southeastern USA (Barnett and Gibson 1975, McLaughlin and Boykin 1988, McLaughlin and Fairbrother 1994). Viruses infecting clovers include peanut stunt virus (PSV), clover yellow vein virus (CYVV), alfalfa mosaic virus (AMV), bean yellow mosaic virus (BYMV), white clover mosaic virus (WCMV), and clover yellow mosaic virus (CYMV; Barnett and Diachun 1985). Infection by these viruses generally has a deleterious effect on clover growth, particularly when plants are stressed by other factors. Gibson et al. (1981) reported that AMV, CYVV, and PSV infection of white clover reduced stolon length and dry weight, leaf dry weight, and rooting of secondary nodes (Table 1). In red clover (*Trifolium pratense* L.), factors related to symbiotic N_2 fixation (nodule weight, number, and leghemoglobin concentration) were reduced by WCMV infection (Khadhair et al. 1984).

Most viruses are transmitted by aphids in a non-persistent manner; viruses acquired when an aphid probes an infected plant do not replicate within the aphid but are carried on its stylet until they are deposited when the aphid probes another plant. Sowing grasses with clover increases the probability that a viruliferous aphid will encounter and deposit the virus in a non-host grass rather than in a host clover, thereby reducing the rate of disease spread in the clover. The same dilution and protection effect applies to mechanically-transmitted viruses such as WCMV, which may be transmitted by harvesting equipment. That this occurs was confirmed in two separate studies. After two years, AMV and WCMV incidence in clipped plots was reduced from 80 to 35% and from 95 to 30%, respectively, when white clover was sown with tall fescue compared with monoculture (Brink and McLaughlin 1990). In a continuously-stocked pasture, rate of PSV infection of white clover in monoculture was greater (3.6 vs. 2.3% infection per month; Fig. 1) than that of clover grown with tall fescue (McLaughlin et al. 1992). In both studies, however, virus disease spread was only delayed by the presence of the grass.

NEMATODE DISEASES IN LEGUME-GRASS SWARDS

Nematodes are another group of pathogens that infect annual and perennial clovers, particularly in the southeastern USA. Nematode species that commonly attack clovers include the root-knot nematode [*M. incognita* (Kofoid & White) Chitwood and *Meloidogyne arenaria* (Neal) Chitwood], the root-lesion nematode (*Pratylenchus* spp.), and the clover cyst nematode [*Heterodera trifolii* (Goffart) Oostenbrink; Leath 1985]. The roots and stems of root-knot nematode infected plants become galled, which reduces water and nutrient uptake and translocation, and eventually reduces productivity of annual clovers (Windham and Pederson 1988) and persistence of perennial clovers (Baxter and Gibson 1959). In contrast, southeastern forage grasses such as bermudagrass and endophyte (*Acremonium coenophialum* Morgan-Jones and Gams)-infected tall fescue possess greater tolerance, and in some cases resistance, to nematodes. Within available bermudagrass cultivars, host efficiency to root-knot nematode varies greatly (Windham and Brink 1991); 'Coastal' bermudagrass is immune to both *M. incognita* and *M. arenaria* (Table 2).

The nematode resistance possessed by

bermudagrass suggests that, like viruses, there may be some benefit to growing a susceptible legume with a resistant grass. In an earlier experiment, Burton et al. (1946) determined whether nematode infection of legumes could be reduced by an associated nematode-resistant bermudagrass. They found that yield of Kobe lespedeza [*Lespedeza striata* (Thumb.) H. & A.] was increased and nematode infection was reduced when the legume was grown with a nematode-resistant bermudagrass strain. The mechanism by which the resistant bermudagrass imparts protection to an associated legume in nematode-infested soil has not been determined. Suppression of nematode infection in legumes by an associated resistant grass has not been consistent, however. When white clover was grown with tall fescue and perennial ryegrass (*Lolium perenne* L.) with and without nematodes, Watson (1990) found that white clover stolon branching and leaf appearance were reduced when nematodes were present, even though both grasses were nematode-resistant (Fig. 2). Thus, the suitability of legume-grass mixtures for nematode suppression will need to be determined for each mixture.

FUNGAL DISEASES IN LEGUME-GRASS SWARDS

Fungi are probably the most widespread diseases of forage legumes and are estimated to cause a 5 to 10% annual loss in clover yield (Leath 1985), although losses in individual cases can be much greater depending on environmental conditions (Scott and Evans 1980) and the clover species involved (Pratt 1984). Fungal pathogens attack and produce decay in all parts of the plant from the seedling stage to maturity. Due to the ubiquitous nature of fungal pathogens, host plant resistance is the only practical means of control. Fungi considered to be major and minor pathogens of clovers are listed by Leath (1985).

Despite their importance and nearly universal occurrence, few studies have compared the severity and impact of fungal diseases in legumes grown with and without grasses. Like virus and nematode infection, however, it is likely that infection by fungal pathogens would be diminished when clovers are grown in association with grass due to a lower density of host species. Although physiogenic in nature with no causal agent, internal crown breakdown is well documented in red clover and arrowleaf clover and causes deterioration of pith in the upper crown region. An experiment involving this disease serves as an illustration of fungal disease interaction in a mixed sward (Pratt and Knight 1983). The authors grew arrowleaf clover at intervals of 5 to 40 cm between plants in monoculture, and at a 40-cm interval overseeded with annual ryegrass. In contrast to other diseases, the authors found that as the planting interval increased (plant density of the susceptible host decreased), clover crown diameter increased, as did the severity of internal crown breakdown (Table 3). When clover was planted with ryegrass at the 40-cm interval, crown diameter and internal crown breakdown were greatly reduced.

CONCLUSIONS

Although forage grasses compete with legumes for nutrients, water, and light, disease incidence of legumes in mixtures is often reduced by the presence of a grass. However, management strategies such as legume-grass mixtures influence only the rate of development and spread of disease infection, and not the eventual outcome, particularly for perennial species (Fig. 1). Incorporation of resistance to a broad array of pathogens remains the most appropriate solution to the problem of diseases in annual and perennial clovers.

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Table 1. Response of white clover to alfalfa mosaic virus (AMV), clover yellow vein virus (CYVV), and peanut stunt virus (PSV) infection.†

Characteristic	Uninfected	AMV	CYVV	PSV
Primary stolon length (cm)	21.8	16.8**	19.6**	12.2**
Secondary stolon length (cm)	36.0	15.8**	26.2**	8.2**
Secondary stolon nodes (no.)	32.0	21.3**	26.3*	16.6**
Rooted sec. stolon nodes (no.)	12.1	4.5**	7.1**	0.7**
Leaf dry wt. (g)	1.1	0.7**	0.9*	0.5**
Stolon dry wt. (g)	0.4	0.3**	0.4*	0.2**

† from Gibson et al., 1981.
*,** Differs from uninfected at P = 0.05 and 0.01, respectively.

Table 2. Number of *Meloidogyne incognita* and *Meloidogyne arenaria* eggs per gram of root on selected bermudagrass cultivars.†

Cultivar	M. incognita		M. arenaria	
Coastcross-1	0	(0.00)‡	170	(4.21)
Coastal	0	(0.00)	0	(0.00)
Tifton 44	163	(1.68)	399	(4.90)
Grazer	110	(1.52)	62	(2.63)
Lancaster	481	(3.45)	239	(3.16)
Tifton 78	1102	(6.59)	275	(5.46)
Alicia	363	(3.93)	327	(3.03)
Maddox	1126	(6.78)	1123	(6.93)
common	2136	(6.91)	313	(5.33)
Callie	1118	(6.67)	223	(4.07)
FLSD (*P* = 0.05)		(1.65)		(1.92)

† from Windham and Brink, 1991.
‡ Arithmetic mean and mean after $\log_e(X + 1)$ transformation (in parentheses).

Table 3. Morphology and internal crown breakdown (ICB) of arrowleaf clover grown at a range of planting intervals and with ryegrass.†

Planting interval	Crown diameter		ICB score‡	
	1981	1982	1981	1982
cm	--------cm--------			
5	0.7 a	0.8 a	0.1 a	0.9 a
10	1.2 b	1.3 b	0.1 a	1.5 b
20	1.8 c	2.2 c	2.3 c	3.4 c
40	2.7 d	3.3 d	2.9 d	3.8 c
40 + ryegrass	1.6 c	1.4 b	0.8 b	0.7 a

† from Pratt and Knight, 1983.

‡ 0 = no ICB symptoms; 1 = internal discoloration but no crown disintegration;
2 = 1 - 20% crown disintegration; 3 = 21 - 50% crown disintegration;
4 = 51 - 100% crown disintegration.
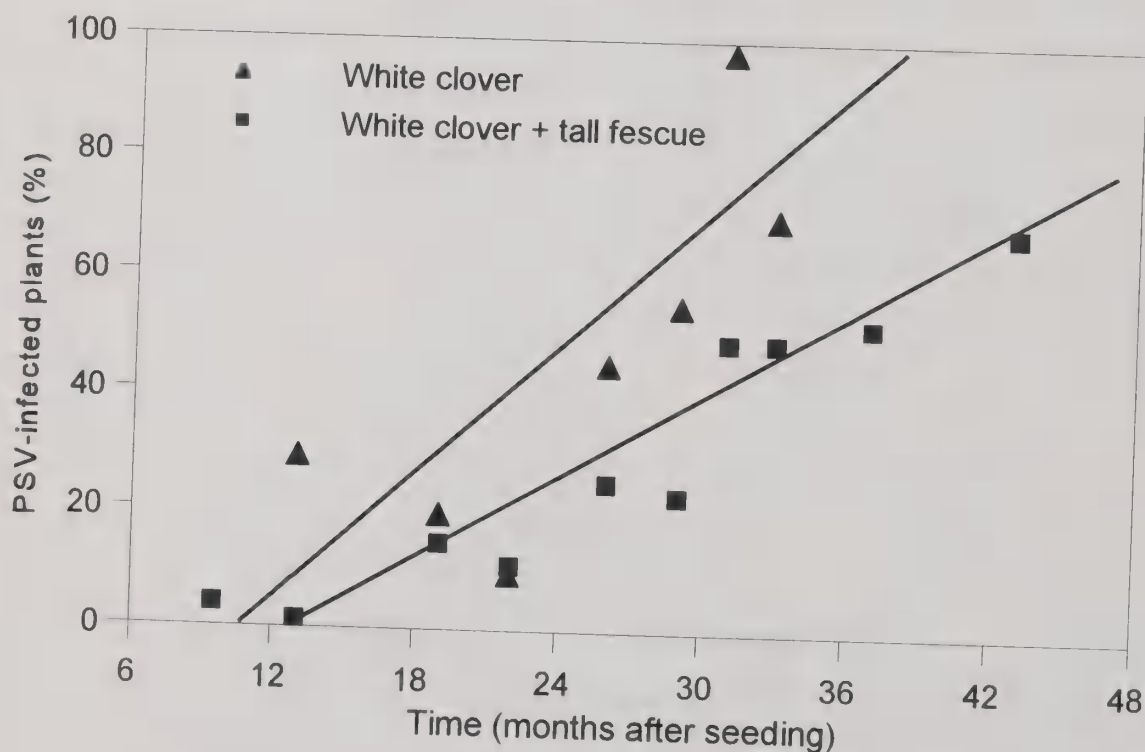
Fig. 1. Peanut stunt virus incidence of white clover grown in monoculture or with tall fescue in a grazed pasture as a function of time (white clover, PSV = -38.2 + 3.6T, r^2 = 0.74; white clover + tall fescue, PSV = -29.2 + 2.3T, r^2 = 0.90 where T = months after seeding); from McLaughlin et al. 1992.
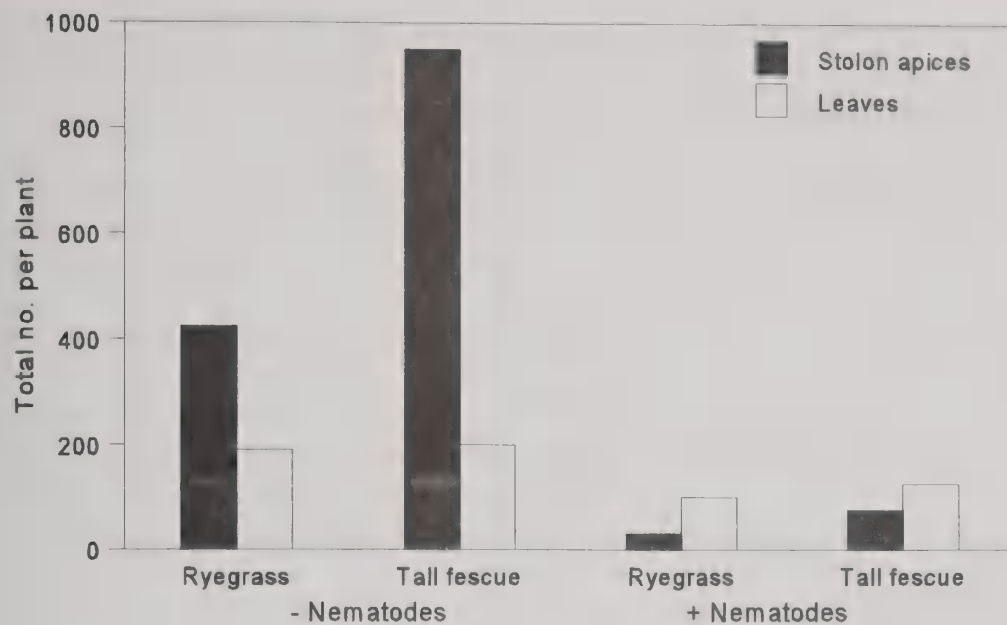
Fig. 2. Morphology of white clover grown with perennial ryegrass or tall fescue with (+) and without (-) nematodes; from Watson 1990.

COMPETITION AND COMBINING ABILITY EFFECTS OF COOL-SEASON LEGUMES AND GRASSES

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ABSTRACT

Forage legumes provide quality forage for grazing livestock as well as a renewable resource of nitrogen for plant growth. One method to enhance pasture forage production is to select complementary species. Mixtures of legumes and grasses may be compatible--avoid competition with each other; compete--make demands on the same resources; or show some form of allelopathy--interact with each other. Our objectives were to evaluate the competition and combining ability effects of cool-season legumes and grasses grown in 1:1 mixtures in the field. The species used were 'Regal' white clover (*Trifolium repens* L.), 'Kenland' red clover (*T. pratense* L.), 'Fergus' birdsfoot trefoil (*Lotus corniculatus* L.), 'Kentucky 31' endophyte-free and -infected tall fescue (*Festuca arundinacea* Schreb.), and 'Martin' tall fescue. Initial results indicate that white clover and tall fescue were compatible with each other (relative yield total, RYT>1.0). Red clover competed with Martin tall fescue (RYT≈1.0), and was incompatible with endophyte-free or -infected Kentucky 31 tall fescue (RYT<1.0). Similarly, birdsfoot trefoil was incompatible with tall fescue (RYT<1.0). A significant positive general combining ability (GCA=415 kg/ha) was found for white clover and a significant negative GCA (-462 kg/ha) for birdsfoot trefoil. Corroborating the RYT data, significant negative specific combining abilities were found for red clover mixed with either endophyte-free (-982 kg/ha) or endophyte-infected Kentucky 31 tall fescue (-1646 kg/ha). Because specific interactions occur between plant genotypes, specific combination of legumes and grasses will need to be evaluated to determine their compatibility.

INTRODUCTION

The addition of legumes to perennial pasture systems can increase the total available forage, forage quality, and reduce the use of nitrogen fertilization. In the USA, the lack of persistence of forage legumes is a major concern and a lack of legume competitiveness with grasses has been listed among the major problems (Matches 1989). Tall fescue is the predominant cool-season forage in the USA and it is estimated that 90% is infected with a mutualistic fungal endophyte (*Acremonium coenophialum* Morgan-Jones & Gams) (Daniels et al. 1985, Shelby and Dalrymple 1987). Some alkaloids produced by tall fescue plants infected with fungal endophytes cause deleterious effects to livestock in the form of reduced growth, conception, milk production, and intolerance to heat stress (Bacon et al. 1977, Hoveland et al. 1983, Hemken et al. 1984, Read and Camp 1986) and some confer beneficial effects to tall fescue in the form of increased plant persistence largely due to enhanced drought and pest tolerance (Johnson et al. 1985, Hardy et al. 1986, Siegel et al. 1987, Clay 1988, Arachevaleta et al. 1989, West et al. 1993). In the USA, losses of cattle grazing tall fescue exceed $560 million annually in reduced calf numbers and $233 million annually in reduced weaning weights (Hoveland 1991). Limiting the dry matter (DM) intake of infected tall fescue is one method of reducing fungal infected-tall fescue related animal disorders (McMurphy et al. 1990). The major reason for planting legumes with endophyte-free tall fescue is to reduce nitrogen (N) fertilizer expenses. One method to increase pasture forage

production and dilute the toxic effects of fungal infected tall fescue is to select complementary legume species. Mixtures of legumes and grasses may be compatible-- avoid competition with each other; compete- -make demands on the same resources; or show some form of allelopathy--interact with each other (Harper 1977). Allelopathic effects of tall fescue on birdsfoot trefoil, red clover, and white clover have been studied (Peters 1968, Peters and Zam 1981, Luu et al. 1989, Pederson 1986). However, limited information is available on interactions among plant species in pasture environments.

RESEARCH OBJECTIVE

One objective of the forage legume research project at the USDA, Agricultural Research Service, South Central Family Farm Research Center located near Booneville, AR is to evaluate the competition and combining ability effects of legumes and grasses grown under simulated pasture conditions.

EVALUATION PROCEDURES AND THEORIES

In one experiment, we studied Regal white clover, Kenland red clover, Fergus birdsfoot trefoil, low-endophyte Martin tall fescue, and endophyte-free and -infected Kentucky 31 tall fescue. In a field experiment, each cultivar entry was hand-transplanted in pure or mixed stands. Individual field plots were 1.2 x 1.4 m in size and plants were spaced on 15-cm centers. Mixtures were planted at a 1:1 ratio alternating entries within and between rows. Treatments consisted of the six pure stands and fifteen mixed stands. All combinations of species mixtures were used, i.e, grass with grass, grass with legume, and legume with legume. The experimental design was a randomized complete block replicated four times. All plots received broadcast fertilization of phosphorus (P) and potassium (K) at the rate of 67 kg/ha in mid-March 1994. The source of P was triple

superphosphate (0-46-0, $N-P_2O_5-K_2O$) and the source K was potash (0-0-60). At the same time plots consisting of grasses only received 67 kg/ha application of N in the form of ammonium nitrate (34-0-0). Plots were harvested twice in 1994 on 6 May and on 13 June.

Two methods were used to evaluate the competition and combining ability effects. Relative yield (RY) and RYT were determined by harvesting a 0.25 m^2 area from the center of each plot at a stubble height of 5 cm. After manual separation of species, DM yield was determined for each component in the mixture. Samples were dried at 70 °C and weighted to determine DM. The RY is the ratio between the yield of a particular species in a mixture and its yield in a pure stand at the same total density. The RYT is the sum of the relative yields for any two species in a mixture. A RYT not significantly different from 1.0 implies that the two species are making demands on the same limiting resources of the environment. A RYT> 1.0 suggests that the species make different demands on resources, avoid competition with each other or are showing some form of symbiotic or synergistic relationship with respect to combined yield. A RYT< 1.0 implies a mutual antagonism in which neither species contributes its expected share to the yield of a mixture. Combining abilities were determined by harvesting the remainder of each plot at a stubble height of 5 cm. Plot fresh weights were recorded, a sub-sample was taken, dried, and DM yield was calculated. The GCA of a species entry is the mean performance of the entry when expressed as a deviation from the mean of all species combinations. Similarly, any particular combination has an 'expected' value which is the sum of the general combining abilities of the two species in the mixture. The deviation of a combination from its expected values is its specific combining ability (SCA). Total digestible DM was calculated by multiplying the

percentage *in vitro* organic dry matter digestion (estimated using near infrared reflectance spectroscopy) times the total DM.

Means and standard errors of means were determined for RYs and RYTs of entries in mixtures. A t-test was used to determine if RYTs were significantly different from unity (1.0). Combining abilities were determined using a diallel analysis of variance (Griffing 1956, Method 1, Model I procedure) and PROC GLM (SAS Institute 1985).

EXPERIMENTAL RESULTS AND DISCUSSION

Variations among mixtures were detected for RY and RYT Tables 1-3). Based on average Rys, white clover, 0.87 > red clover, 0.54 > birdsfoot trefoil, 0.18 for competitiveness in legume-legume mixtures (Table 1). Among grass-grass mixtures E+Kentucky 31, 0.58 = E- Kentucky 31, 0.56 > Martin, 0.33 tall fescues in competitiveness (Table 2). In mixtures of E+Kentucky 31 tall fescue with a legume or E- Kentucky 31 tall fescue with a legume, white clover, 0.59 > red clover, 0.32 = birdsfoot trefoil, 0.27 for competitiveness. However, competitiveness of white clover, 0.68 > red clover, 0.48 > birdsfoot trefoil, 0.34 in mixtures of Martin tall fescue with a legume (Table 3).

Differences in total DM and total digestible DM were attributed to species mixtures (Tables 4-5). In general for total DM production, the yields of mixtures of white clover + grass; 7,915 kg/ha = grass + grass; 7,605 kg/ha = legume + legume; 7,401 kg/ha > red clover + grass; 6,476 kg/ha = birdsfoot trefoil + grass; 6,432 kg/ha. For digestible DM production the yields of legume + legume; 6,087 kg/ha = white clover + grass; 5,903 kg/ha > grass + grass; 5,272 kg/ha = birdsfoot trefoil + grass; 4,704 kg/ha = red clover + grass; 4,686 kg/ha.

In terms of their combining ability, significant GCA effects occurred for these data (Table 4). In general, adding white clover to a mixture will significantly increase (+GCA) the total harvested DM yield and digestible harvested DM yield. Conversely, incorporating birdsfoot trefoil to a mixture will significantly decrease (-GCA) the total harvested DM yield. Adding white clover also significantly increased the digestible harvested DM yield of a mixture, while adding E- Kentucky 31 tall fescue significantly reduced the digestible harvested DM yield (Table 5).

Significant SCA effects also occurred for these data (Table 4). Adding red clover to either Kentucky 31 (E+ or E-) tall fescue will significantly decrease (-SCA) the total harvested DM yield and digestible harvested DM yield. Also based on the SCA values, pure stands of white clover and birdsfoot trefoil yielded lower in total DM than their expected yields (based on GCA effects). For digestible harvested DM, pure stands of Kentucky 31 tall fescue (E- or E+) yielded higher than their expected yields. The digestible harvested DM of white clover followed the same trend as it did for total harvested DM, a lower than expected value.

CONCLUSIONS

Plant genotype interactions were observed in this experiment. Regal white clover combined well with the three tall fescue genotypes, whereas, Kenland red clover combined well with Martin tall fescue but not Kentucky 31 tall fescue. Fergus birdsfoot trefoil had a significant negative GCA for total DM yield suggesting that it may be out of its adaptation range. With regard to the experimental methods, the diallel analysis of variance is an excellent tool for evaluating combining abilities among legumes and grasses. Because specific interactions occur between plant genotypes,

specific combination of legumes and grasses will need to be evaluated to determine their compatibility.

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Table 1. Relative yield (RT) and relative yield total (RYT) for legume mixtures[1]

Species (a)	Species (b) (RY)	Species (a) (RY)	Species (b)	RYT
WC	RC	0.88	0.31	1.20
WC	BT	0.86	0.10	0.96*
RC	BT	0.78	0.27	1.05*

* Not significantly different from unity (1.0), $P > 0.10$ (T-test).
[1] WC, 'Ladino' white clover; RC, 'Kenland' red clover; and BT, 'Fergus' birdsfoot trefoil.

Table 2. Relative yield (RT) and relative yield total (RYT) for grass mixtures[1]

Species (a)	Species (b)	Species (a) (RY)	Species (b) (RY)	RYT
TF (E-)	TF (E+)	0.52	0.50	1.02*
TF (E-)	TF (M)	0.65	0.33	0.98*
TF (E+)	TF (M)	0.61	0.34	0.95*

* Not significantly different from unity (1.0), $P > 0.10$ (T-test).
[1] TF (M), Low endophyte 'Martin' tall fescue; TF (E-), endophyte-free 'Kentucky 31' tall fescue; and TF (E+), endophyte-infected 'Kentucky 31' tall fescue.

Table 3. Relative yield (RT) and relative yield total (RYT) for legume-grass mixtures[1]

Species (a)	Species (b)	Species (a) (RY)	Species (b) (RY)	RYT
WC	TF (E-)	0.60	0.55	1.15*
RC	TF (E-)	0.38	0.47	0.85
BT	TF (E-)	0.33	0.47	0.80
WC	TF (E+)	0.58	0.63	1.21
RC	TF (E+)	0.26	0.60	0.86
BT	TF (E+)	0.21	0.62	0.83
WC	TF (M)	0.68	0.49	1.17
RC	TF (M)	0.48	0.48	0.96*
BT	TF (M)	0.34	0.46	0.80*

* Not significantly different from unity (1.0), $P > 0.10$ (T-test).

[1] WC, 'Ladino' white clover; RC, 'Kenland' red clover; BT, 'Fergus' birdsfoot trefoil; TF (M), low endophyte 'Martin' tall fescue; TF (E-), endophyte-free 'Kentucky 31' tall fescue; and TF (E+) endophyte-infected 'Kentucky 31' tall fescue.

Table 4. Total harvested dry-matter yield (kg/ha), general combining ability (GCA, kg/ha), and specific combining ability (SCA, kg/ha) for mixtures of species (a) and species (b)[1]

Species (a)	TF (E+)	TF (E-)	TF (M)	WC	RC	BT
Species (b)						
TF (E+)	8,280 a	7,826 ab	7,498 abcd	7,903 ab	5,615 f	6,277 cdef
SCA	807*	567	-27	120	-1,646**	-629
TF (E-)	6,572 bcdef	7,028 abcdef		7,505 abcd	7,942 ab	6,064 def
SCA		-16	195	373	-982*	-120
TF (M)			7,495 abcd	7,901 ab	7,750 abc	6,449 bcdef
SCA			-81	67	437	-509
WC	8,127 a			7,064 abcdef		8,159 a
SCA				-1,029*	588	910
RC	7,870 ab				7,263 abcde	
SCA					214	1,176*
BT						5,924 ef
SCA						-415
GCA	105	-109	157	415*	-107	-462*

Means followed by the same letters are not significantly different at $P < 0.05$.

*, ** Significantly at $P < 0.05$ and $P < 0.01$, respectively (protected LSD test).

[1] WC, 'Ladino' white clover; RC, 'Kenland' red clover; BT, 'Fergus' birdsfoot trefoil; TF (M), low endophyte 'Martin' tall fescue; TF (E-), endophyte-free 'Kentucky 31' tall fescue; and TF (E+) endophyte-infected 'Kentucky 31' tall fescue.

Table 5. Digestible harvested dry-matter yield (kg/ha), general combining ability (GCA, kg/ha), and specific combining ability (SCA, kg/ha) for mixtures of species (a) and species (b)[1]

Species (a)	TF (E+)	TF (E-)	TF (M)	WC	RC	BT
Species (b)						
TF (E+)	5,830 abcde		5,507 cdefg		5,182 defghi	
	5,944 abcd	4,106 I	4,675 fghi			
SCA	635*	554	2	-5	-1,316**	-505
TF (E-)		4,758 efghi		5,126 defghi		5,787 abcdef
	4,385 hi	4,808 efghi				
SCA		48	189	82	-793*	-129
TF (M)			5,232 defghi		5,978 abcd	5,569 bcdefg
	4,630 ghi					
SCA			67	45	163	-535
WC				5,943 abcd	6,679 ab	6,824 a
SCA				-759*	504	891*
RC	6,498 abc				5,823 abcde	
SCA					175	1,092**
BT						4,758 efghi
SCA						-407
GCA	-118	-361**	-133	635**	109	-133

Means followed by the same letters are not significantly different at $P < 0.05$.
*, ** Significantly at $P < 0.05$ and $P < 0.01$, respectively (protected LSD test).
[1] WC, 'Ladino' white clover; RC, 'Kenland' red clover; BT, 'Fergus' birdsfoot trefoil; TF (M), low endophyte 'Martin' tall fescue; TF (E-), endophyte-free 'Kentucky 31' tall fescue; and TF (E+) endophyte-infected 'Kentucky 31' tall fescue.

GERMPLASM CONTRIBUTIONS TO IMPROVE BIRDSFOOT TREFOIL INTERACTIONS WITH COMPANION GRASSES

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ABSTRACT

Broadleaf birdsfoot trefoil (*Lotus corniculatus* L.) is a non-bloating herbage legume with high quality. There are many advantages to growing and managing birdsfoot trefoil with companion grasses for hay or pasture. In birdsfoot trefoil-grass mixes, growth habit of the grass and birdsfoot trefoil cultivars may affect their competitiveness, yield, and herbage quality. Prostrate forms of birdsfoot trefoil may retain more photosynthetic tissue than upright forms, favoring carbohydrate availability and persistence through reseeding. Most grasses are more competitive than birdsfoot trefoil when they compete for nutrients, moisture, and light. Competition for light in the sward canopy is a major factor in interspecific competition of grasses and legumes; interspecific competition can reduce the yield of both herbage components. Management, such as defoliation practices, can modify the extent of interspecific competition and promote mutual compatibility. A compatible relationship will vary with birdsfoot trefoil cultivar selection, grass species/cultivar, environment, seasonal management, and interactions among these major components. This paper will present a chronological perspective of strategies that can be used to promote birdsfoot trefoil-grass compatibility.

INTRODUCTION

Broadleafed birdsfoot trefoil is a cross-pollinated, perennial legume used for pasture, hay and silage production. It does not cause bloat and can be managed to reseed to maintain stands. Nineteenth-century reports show it grew naturally in many European pastures and was a good feed for cattle and horses. However, it was not until after 1900 that birdsfoot trefoil was cultivated in Europe (MacDonald 1946). Birdsfoot trefoil is native to Europe, North Africa, and parts of Asia, but the greatest genetic diversity occurs in the Mediterranean basin, which is considered its regional center of origin.

Birdsfoot trefoil is not native to the Western Hemisphere, and it is not certain from where or when it was introduced into North America. The perception of birdsfoot trefoil as an herbage crop is based on the early experiences of producers and researchers in the 1940-50's who discovered its value and utility. The successes and failures by the first generation of users have been used to justify birdsfoot trefoil use or disuse by subsequent generations. Early cultivars have also influenced the perception of what researchers expect from interactions between birdsfoot trefoil and companion grasses. This paper examines the perceptions and misconceptions that have evolved for birdsfoot trefoil persistence with grasses and the role that exotic germplasm may have to change those perceptions.

EMPIRE: Birdsfoot Trefoil's Beginning in the North America

Birdsfoot trefoil first received recognition in North America in 1934 when a naturalized stand was found growing in Albany County, New York (Johnstone-Wallace 1938). Farmers in the area grew birdsfoot trefoil, probably introduced in contaminated ship ballast, for 20-25 years before it was identified by Professor Johnstone-Wallace (MacDonald 1946). This population had naturalized in an ungrazed open field with the native grasses poverty grass (*Danthonia spicata* L.) and Canada bluegrass (*Poa compressa* L.) and the escaped introductions Kentucky bluegrass (*Poa pratensis* L.), meadow fescue (*Festuca pratensis* Huds.)

and timothy (*Phleum pratense* L.) (MacDonald 1946). Seeds of this naturalized population were increased and disseminated for approximately 10 years before it was named 'Empire' (MacDonald 1957). Throughout the remainder of this paper, Empire will be used to refer to the original unnamed naturalized population and the cultivar. In Europe, birdsfoot trefoil had been recognized and promoted as a valuable forage crop nearly 20 years by the time of its recognition in New York, even though it had received minor evaluation by Agricultural Experiment Stations around 1890 (Anonymous, 1890).

After its discovery, there were favorable reports about the attributes of Empire which created excitement among producers and seedsmen to establish birdsfoot trefoil as the "poor man's alfalfa." Reports of a persistent and high producing legume that could be hayed or directly grazed on soils with poor drainage, low fertility, or acid conditions were hard to resist. Empire was grown on a wide range of soils and conditions including droughty, infertile, acid, or mildly alkaline soils, mine spoils, and under saline and waterlogged conditions. In some situations Empire tolerated the adverse soil conditions. As demand for this "wonder" legume increased, seed of Empire was disseminated widely to fulfill the expectations of producers.

Environmental Limitations to the Widespread Use of Empire

As birdsfoot trefoil spread beyond New York, especially south, reports of stand failures and dissatisfaction became more common (Krenzin 1953, Miller et al. 1964). Early reports stated that birdsfoot trefoil was a perennial with a longevity comparable to alfalfa (*Medicago sativa* L.) (MacDonald 1946). Longevity was not reported for individual plants, but the characterization of birdsfoot trefoil as a long-lived perennial persists. Later reports continued to quote

earlier characterization of birdsfoot trefoil as a long-lived perennial (Wheeler 1950, McKee and Schoth 1949, Henson and Schoth 1962, Null and Wheaton 1978). It was recognized that stands could be maintained through reseeding, but clearly, the perenniality of birdsfoot trefoil received greater promotion. The production of seed was important for the commercial dissemination of this crop to new areas rather than reseeding to maintain stands. Early recommendations generally ignored management for reseeding, but later, producers received advice to allow for an occasional seed crop to maintain stands (Null and Wheaton 1978).

Pure stands of birdsfoot trefoil are not as desirable as mixtures with grasses, because pure stands thin with time and weed control becomes a problem. Companion grasses utilize the nitrogen fixed by the birdsfoot trefoil and fill vacant areas in the stand where weeds would otherwise grow. Competition for light in the sward canopy is a major factor limiting successful birdsfoot trefoil establishment with grasses. Trefoil seedlings are small, slow to establish, and cannot tolerate much competition, thus competition must be controlled. As previously mentioned, Empire naturalized with Kentucky bluegrass, timothy, and meadow fescue which are good grass companions because they grow slowly during birdsfoot trefoil establishment. However, orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), and smooth bromegrass (*Bromus inermis* Leyss.) can be compatible with birdsfoot trefoil when management reduces the competitive effects of these more aggressive grasses.

Most research on birdsfoot trefoil-grass compatibility has been to identify characteristics of grasses that are detrimental to birdsfoot trefoil. As an extension of that research, some breeding has been practiced to develop grasses more compatible with birdsfoot trefoil. For example, orchardgrass

selected for low tiller number, low spring canopy height, and late maturity showed improved compatibility with birdsfoot trefoil (Short and Carlson 1989). However, no grass cultivars with improved compatibility with birdsfoot trefoil have been developed in North America. Thus, the management of competition by the various grasses has become a key to successful birdsfoot trefoil-grass systems. We know that tiller production can be an important character regulating competition by the companion grass (Kays and Harper 1974). Birdsfoot trefoil can be detrimentally shaded when grown in mixtures with tall growing grasses that form solid or dense stands. Grazing or haying practices that reduce grass competition and promote trefoil growth may involve early haying, early and close grazing, or intensive rotational grazing. Prescribed burning can temporarily injure and slow the spring growth of the grass, and reduces thatch to encourage the germination and establishment of new trefoil seedlings. Local environmental conditions, including length of photoperiod, temperature extremes, distribution and form of precipitation, and level of humidity are important components to managements seeking to promote birdsfoot trefoil persistence.

Consider the environment where Empire had become naturalized. Albany, New York is located at approximately 42.5 °N, 74 °W (Table 1). Maximum daylength is 15.3 hours on 21 June (U.S. Naval Observatory 1979). The mean high and low temperatures are 20.5 and 1 °C on 21 June and 21 Dec., respectively (U.S. Department of Commerce, 1968). The length of the frost-free growing season is 150 days, commencing about 30 Apr. Compare the statistics in Table 1 for Albany, New York with locations like Columbia, Missouri (approximately 39 °N, 93 °W), Corvallis, OR (approximately 44.5 °N, 123 °W), Duluth, Minnesota (49 °N, 96 °W.), or Fresno, California (approximately 36.5 °N, 120 °W), which are also locations within the area of adaptation for birdsfoot

trefoil. The environmental differences are apparent, but the effects of these differences on adaptation of birdsfoot trefoil are not well researched or understood. The erroneous assumption has been that birdsfoot trefoil cultivars will perform acceptably at all locations within birdsfoot trefoil's area of adaptation.

New Cultivars from New Germplasm Introductions

As Empire seed was distributed, researchers recognized the possibility to develop improved cultivars that could perform in environments and interactions with other grasses where Empire had not naturalized. Because, birdsfoot trefoil is a cross-pollinated species, a practical approach was to employ mass selection or a modification of mass selection, like recurrent selection, to genetically shift Empire toward better adaptation.

It has been a common practice to develop a cultivar from a plant introduction (PI) by multiplication through mass selection. The selection method is effective if sufficient genetic variation is available in the population to result in a genetic shift of the population. It was reasonable to assume that the genetic constitution of Empire was heterogeneous and capable of manipulation to develop improved populations. Within two decades after the discovery of Empire, 14 Agricultural Experiment Station and USDA breeding programs had been initiated using Empire as the genetic base. Almost three decades after the discovery of Empire, six United States varieties had been developed, and the number of breeding programs had declined to six. Of the remaining breeding programs, most had shifted away from selection within Empire as their gene source, in favor of exotic germplasm.

There are two distinct types of birdsfoot trefoil, Empire and European, that constitute

the germplasm from which most United States and Canadian cultivars are derived. European- and Empire-types are distinct. The Empire-derived cultivars generally are finer stemmed, more prostrate in growth habit, later to flower, more indeterminate in growth and flowering habit, and slower in seedling growth and recovery growth rate after harvest than are European-types. Six decades after the discovery of Empire, at least 25 cultivars, which include experimental germplasms, have been developed in the United States and Canada, but fewer than 10 are commercially available.

Novel populations resulting from mixtures of diverse germplasm, often from intercrossing Empire and European germplasm, have resulted in the improved performance of birdsfoot trefoil beyond the range where Empire performed well. Improved yield was one of the first traits to be selected for in birdsfoot trefoil. Limited success was obtained from selection within Empire. Empire is considered to be a decumbent or prostrate cultivar, making the harvest of herbage difficult unless the trefoil herbage is supported upright by a companion grass. Without obvious morphological variation for growth habit in Empire, early attention was given to upright growth form of cultivars grown in Europe. The cultivar 'Viking' was the first cultivar in North America not derived specifically from Empire. Viking was developed from a mix of Empire and Danish germplasm (probably the cultivar Roskilde), but wasn't released for 10 years after the naming of Empire in 1947 (MacDonald 1957). Viking, being more upright yielded 15-20% more herbage than Empire in New York. However, the prostrate growth form remained in favor for pasture and grazing because it appeared to persist better than Viking. Recurrent selection of Empire for use in Missouri pastures resulted in the cultivar Dawn (Beuselinck 1994).

A second important trait selected for was winterhardiness. Empire is moderately winter-hardy in the northern United States and southern Canada, but severe winter conditions or winters with variable temperatures were often detrimental to stands. Where there are extreme winters, in North America particularly above 40 °N latitude, snow cover is critical to birdsfoot trefoil survival (Table 1, Duluth, MN),. Although selection was able to improve harvest yield of Viking over Empire, severe winter damage to Viking stands led to the search for improved winterhardiness. The Russian cultivar 'Morshansk 52' (PI 258467) expressed greater winterhardiness and upright growth and was used as the genetic source for the breeding of the cultivars 'Leo' (Bubar 1964) and 'Carroll' (Carlson 1973). In other locations where Empire was introduced, the winter conditions were not as severe as the environment where Empire naturalized. Winter dormancy expression by Empire or Viking was not conducive to the longer season of production. The cultivars 'Cascade' and 'Granger' were developed from the French accessions F.C. 20153 and F.C. 22557, respectively, for areas of the Pacific Northwest where winter temperatures are not severe and the growing season is longer (Table 1, Corvallis, OR).

The cultivar 'Norcen' was derived from the combination of best performing germplasm from the three birdsfoot trefoil breeding programs in Missouri, Illinois, and Iowa, respectively (Miller et al. 1983). Thus, the genetic background of Norcen is likely derived from Empire, Morshansk 528, and Danish germplasm. The cultivars 'Fergus' and 'GA 1' are examples of cultivars that were developed for the southeastern United States from remnants of experimental research trials of birdsfoot trefoil introductions that intercrossed and developed into ecotype cultivars via natural selection with added breeder-directed selection. Fergus is derived from French germplasm and Empire (Taylor and

Templeton 1985) and GA 1 traces its ancestry to the Brazilian PI 244036, and the cultivars 'Kimey,' Granger, and Empire (Fales et al. 1986). Kimey was developed from PI 289776 from Chile (Dolan and Sherring 1981). The cultivar 'AU Dewey' is unique among the "southern" birdsfoot trefoil cultivars in that it is derived from the Yugoslavian PI's 188556 and 251558 that had specific attributes desirable for environmental conditions of the South (Pedersen et al. 1986) and does not include Empire in its background.

Strategies for Unresolved Problems of Persistence

Birdsfoot trefoil evolved with grasses, and decades of pastoral agriculture have demonstrated the ability of birdsfoot trefoil to persist with different grass species in North America. Grasses are generally more competitive than birdsfoot trefoil in any birdsfoot trefoil-grass system, so a successful system maintains a balance of competition between the two forages. Competition is not static or continuous between the birdsfoot trefoil or grass in a system, providing opportunities for weak or diseased plants to recuperate or dead plants to be replaced with new plants. However, modern agriculture practices can stress the balance of competition, leading to the loss of the birdsfoot trefoil in a birdsfoot trefoil-grass system.

A monoculture is the simplest forage system in which to study plant-to-plant competition; i.e., in a stand of birdsfoot trefoil grown alone, competition occurs between two or more neighboring plants with similar needs for resources for growth and expression of growth. Competition for resources becomes more complex when two or more species comprise the forage system. Monocultured birdsfoot trefoil is less desirable than a mixture with grasses, yet interactions between the grass and birdsfoot trefoil in mixtures are inherently more difficult to

understand. Managing plant-to-plant competitiveness in a birdsfoot trefoil-grass system requires some understanding of the biology of each forage component. No cultivars of birdsfoot trefoil or grass have been developed for mutual compatibility, because it has been difficult to assess plant-to-plant competitiveness within mixtures. So, the best opportunity for improving the persistence of birdsfoot trefoil in a birdsfoot trefoil-grass system is to understand that birdsfoot trefoil is the weak partner of a complex balance of plant-to-plant competition. New strategies to resolve the persistence problem that have come from the study of the biology of birdsfoot trefoil are: 1) earlier flowering to promote improved seed production in southern latitudes and better seed quality, 2) disease resistance to improve longevity of an individual plant, and, 3) vegetative reproduction by rhizomes to improve plant longevity and decrease dependence on reseeding.

Resolution of the problems of competitiveness and persistence with grasses lies in understanding the biology of birdsfoot trefoil. It is an indeterminate flowering, herbaceous, cool-season forage legume. Birdsfoot trefoil is a long-day plant with most North American cultivars requiring a 16- to 18-hour day for full flowering; the critical photoperiod is 14.0 to 14.5 h (Joffe 1958, McKee 1963). Because of this adaptation for long days with cool temperatures, commercial seed is produced predominantly in the northern regions (above 46 °N Lat.) of Michigan, Wisconsin, Minnesota, and southern Canada. Seed yields in commercial areas are encouraged by a short period of profuse flowering and cooler temperatures (McGraw et al. 1986). By the time plants break dormancy in the spring and reach flowering stage daylengths are well beyond the critical photoperiod in the commercial seed production areas. Flowering is not as profuse in the southern regions of adaptation and occurs over a longer period. In the southern areas of

adaptation, birdsfoot trefoil begins flowering earlier in the year when daylengths are shorter than in northern areas, because plants are exposed earlier to air and soil temperatures conducive to plant growth (Table 1).

The seed production potential of birdsfoot trefoil in southern latitudes is lower compared to northern latitudes of North America (McGraw et al. 1986). Locations below 40 °N Lat. (Table 1) do not have daylengths that meet the photoperiod requirements for the full-flowering of most North American birdsfoot trefoil cultivars (McKee 1963). Most of the current cultivars have been developed for northern (at or above 40°N Lat.) conditions and are derived from northern European and Empire germplasm. In southern locations (like Columbia, MO; Table 1) the quantity and quality of seed produced per flower declines over the season (Beuselinck and McGraw, 1988). Seed size and quality affect seedling vigor (Beuselinck and McGraw 1983, McKersie and Tomes 1982), which affect seedling competitiveness to establish and maintain stands (Twamley 1967). Cycles of poor seed production and low quality seed lead to poor seedling establishment and survival and stand decline. Seed production of birdsfoot trefoil is critical in southern latitudes to insure long-term persistence; but the production and quality of seed are inferior to those resulting from stands in northern latitudes.

The sum of what we know about flowering and reproductive success in birdsfoot trefoil suggests that populations selected for a shorter photoperiod requirement would flower earlier in southern areas of adaptation when temperatures are cooler (Beuselinck and McGraw 1988). There are many plant introductions that could be used to develop early flowering lines. Germplasm from the Mediterranean or North Africa would be

a good candidate. Naturalized populations or cultivars from South America, particularly Brazil, Uruguay, or northern Argentina or Chile could also be a source of early flowering. The germplasm GA 1 (Fales et al. 1986) may have good natural reseeding capability derived from the Brazilian germplasm in its background. Plants selected for earlier flowering should result in higher reproductive success, i.e., flowers that produce a greater number of seed and seed with greater mass should improve natural reseeding in birdsfoot trefoil-grass systems grown in more southern latitudes. Selection for earlier flowering cultivars should not have an effect on time of flowering in commercial North American seed production areas.

To ensure stand persistence of current cultivars a common management recommendation is to promote the production of some seed for reseeding by delaying the harvest of early growth (Taylor et al. 1973). Stockpiling is the practice of accumulating herbage by delaying grazing or haying until some later time, usually the fall, when it is needed. It can be a practical way to promote reseeding, but success with stockpiling birdsfoot trefoil is favored by dry, cool environments (Marten and Jordan 1979). Hot, humid climates impair stockpiling because Rhizoctonia foliar blight (*Rhizoctonia solani* Kuehn) damages leaves and stems, lowering forage productivity and quality (Beuselinck et al. 1984), making it an impractical means to promote reseeding in humid climates. The search for resistance to foliar diseases among exotic germplasm may aid reseeding by allowing stockpiling in environments where it is now impractical. The management of the companion grass in a birdsfoot trefoil-grass system adds additional complexity to seed production. Competition from grass can delay birdsfoot trefoil flowering, reduce regrowth, subsequent flowering, and reduce seed yield, and create a favorable environment for pathogens.

Early Flowering can Enhance Avoidance of Seed Predators

The trefoil seed chalcid, *Bruchophagus platypterus* (Walker), is a small, black, wasp-like, host-specific insect that can greatly reduce seed yields by parasitizing seeds. Fertilized females are attracted to seed pods by the presence of volatile compounds that elicit landing and egg laying behavior (Kamm 1989). Eggs are laid in young developing seed pods, and the larvae feed inside the maturing ovule, leaving only a hollow, inviable seed. It is estimated that commercial seed yields may be reduced as much as 40% or more by this pest. Pesticides do not effectively control the seed chalcid, so growers must rely on cultural practices to reduce seed losses. Large amounts of seed left on the ground after harvest may increase infestations the following year. In field investigations of plant introductions at Columbia, Missouri, little resistance to this seed--destroying pest was observed. However, it is a practice to reduce chalcid populations in seed fields by avoiding delayed, late-season seed harvest, and by burning or burying combine trash after harvest to destroy infested seed. But, burning may not be practical in a birdsfoot trefoil-grass system. Thus, it is logical to encourage the early production of seed in the growing season where natural reseeding is necessary for stand persistence. Early flowering cultivars should be able to avoid chalcid infestation while later flowering cultivars will be subject to greater chance for infestation and parasitism.

Disease Resistance to Increase Persistence

Birdsfoot trefoil is recognized as a long-lived perennial, but the recognition is not completely valid. In this naturally-reseeding forage crop, persistence of the stand can be confused with individual plant persistence; the two are not synonymous or mutually exclusive. Reseeding may account for the majority of plants in old birdsfoot trefoil stands (Miller et al. 1964). To reiterate, particular environmental conditions are important elements to birdsfoot trefoil persistence.

Crown- and root-rots are the most important diseases of birdsfoot trefoil (Seaney and Henson 1970). Plants generally live for about 2-4 years with losses of 68 to 88% of stands by the end of the second year, with over 80% of surviving plants badly diseased by root-rot (Henson 1962). Birdsfoot trefoil stands survive for only two or three years in the southeastern United States due to crown- and root-rot diseases (Drake 1958). Two years after seeding in Missouri, 90% of stands were lost, regardless of the management practices used (Beuselinck et al. 1984). Severe loss from these diseases is usually associated with warm weather and high humidity, and thus diseases are of greater importance in the South than in the Northeast or North Central United States.

Birdsfoot trefoil performs like a biennial in southern latitudes because of diseases and reduced reseeding (Beuselinck et al. 1984, Beuselinck and McGraw 1988). As already discussed, plant populations can decrease significantly due to crown- and root-rot diseases even where natural reseeding is promoted (Miller et al. 1964). Because no single organism has been identified as the primary cause of crown- and root-rot diseases, attempts to improve stand persistence of birdsfoot trefoil have yielded limited success. The predominance of the pathogens involved with the disease change with the geographic environment in which the trefoil is grown (Seaney and Henson 1970), and the extent of root-rot decay differs by location (Ostazeski 1972). Poor stand persistence of all birdsfoot trefoil cultivars may be due to the relatively close ancestry among the cultivars. As already noted, with few exceptions, Empire is a common ancestor in most United States cultivars.

Because growth environments for birdsfoot trefoil are so diverse and the organisms involved with the disease so variable, it is unlikely that selection for root- and crown-rot resistance at one location would hold up at another location; resistance to the disease organisms only at the location where the selections are made would be an unavoidable result. In an attempt to develop root- and crown-rot resistant populations seven locations in the United States are practicing a cooperative selection scheme. The scheme, termed convergent-divergent selection (Lonnquist et al. 1979) should aid in preventing location specific resistance. The initial population for this selection procedure is the germplasm 'MU-81,' which is comprised of germplasm from 56 plant introductions representing 20 countries (Beuselinck and McGraw 1986).

Rhizomes, a Novel Approach to Persistent Birdsfoot Trefoil

Birdsfoot trefoil typically has a well-developed taproot with numerous lateral branches that develop in the upper 30-60 cm of the soil profile. The taproot does not penetrate as deeply as alfalfa, but the distribution of branch roots in the upper soil is more extensive. Plant species exhibiting rhizomes are capable of producing new roots and shoots seasonally and spreading vegetatively. Since new shoots and roots can be initiated from rhizomes seasonally, the chances of plant survival and stand persistence increase. Therefore, a rhizomatous habit would be useful for increasing birdsfoot trefoil persistence. Wild *L. corniculatus* germplasm from Morocco (Beuselinck 1994) that produces rhizomes has been transferred into the germplasm of commercial cultivars (Beuselinck et al. 1996) and developed into the cultivar 'ARS-2620' recently released by the USDA-ARS. The need for rhizomes as a means to improve the persistence of birdsfoot trefoil has been conjectural; ARS-2620 provides the first opportunity to test this strategy.

Wild Germplasm or Hybridization with Other Species May Aid the Development of Persistent Birdsfoot Trefoil

Considerable variability exists within birdsfoot trefoil germplasm for further selection of new cultivars. Yet the germplasm accessions held in the germplasm banks worldwide need further evaluation to determine if there is sufficient variability for important traits to continue to improve the productivity of birdsfoot trefoil. Although plant introductions provide a diverse array of genes, this diversity usually cannot be quickly developed or incorporated into agronomically-well-adapted materials. Birdsfoot trefoil is used for its herbage rather than grain so it is relatively undomesticated when compared to grain crops like corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), or soybean (*Glycine max* L.). Thus, the improvement of birdsfoot trefoil has not been hampered by the introduction of new germplasm as much as the highly-domesticated crops.

Various breeding methods are available, or are in development, for improving certain traits in birdsfoot trefoil. These methods include interspecific hybridization, tissue culture, protoplast fusion, and genetic transformation technology. Interspecific hybridization of birdsfoot trefoil with other closely related diploid species offers a means of improving certain traits (Williams 1987). For example, big trefoil (*Lotus uliginosus* Schk.) produces rhizomes and therefore has been used in matings to try to transfer that trait to birdsfoot trefoil (Keim 1952, Bent 1962, Williams and Williams 1981). Big trefoil is a diploid ($2n=2x=12$), but the chromosome complement can be doubled using colchicine to facilitate matings with birdsfoot trefoil. Williams and Williams (1981) obtained several $4x$ big trefoil X birdsfoot trefoil hybrids through embryo culture, but their hybrids do not produce rhizomes. The limited success of interspecies crosses with birdsfoot trefoil

demonstrates the possibility for genetic improvement beyond the limitations of a single species that could lead to more aggressive cultivars.

Conclusions

The discovery and spread of Empire generated a hope among producers for a high quality legume for their pastures. Empire naturalized with grasses that did not overly compete for essential components needed for the persistence and survival of the birdsfoot trefoil. Plantings in new environments and in mixtures with more aggressive grasses to meet the demands of agriculture made it apparent that Empire had biological limitations in its ability to fulfill all expectations. The breeding and introduction of new birdsfoot trefoil germplasm from Europe led to solutions to problems encountered with Empire. Introduced germplasm has contributed to the development of superior cultivars for areas of the United States and Canada. Still, continued advancements for birdsfoot trefoil with greater adaptation and better persistence will require novel approaches and introduced germplasm can make vital contributions toward this goal. New strategies will seek to improve the persistence of birdsfoot trefoil through earlier flowering, improved disease resistance, and the introduction of rhizomes. Some plant introductions can be expected to perform as well as or better than the commercial cultivars for many traits. These plant introductions could receive further evaluation to determine if they can contribute to more persistent birdsfoot trefoil cultivars. The development of new grass cultivars with characteristics that promote birdsfoot trefoil survival could offer opportunities to develop new management strategies for improved productivity and quality.

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Table 1. Climatic data[†] for selected United States locations within area of adaptation for birdsfoot trefoil

Location	N Latitude Photoperiod§	W Longitude	Mean °C[‡]	Mean °C	Frost-free	Frost-free
	degrees hours	degrees	21 June	21 Dec.	date	days
Albany, NY	42.5 15.2	74	21 (16 - 26)	1 (-4 - 6)	30 Apr.	150
Columbia, MO	39.0 14.8	93	26 (20 - 33)	4 (1 - 7)	15 Apr.	195
Corvallis, OR	44.5 15.4	123	16 (8 - 21)	7 (2 - 8)	30 Apr.	180
Duluth, MN	46.5 16.3	96	20 (14 - 26)	-3 (-8 - 2)	>30 May	<120
Fresno, CA	37.5 14.5	120	27 (17 - 36)	7 (5 - 9)	28 Feb.	300

[†]Compiled from U.S. Dept. of Commerce (1968).
[‡]Mean temperature is followed in parentheses by mean minimum and maximum temperatures.
§Maximum number of hours between sunrise and sunset on 21 June. Computed from U.S. Naval Observatory (1979).

ENVIRONMENTAL AND MANAGEMENT FACTORS AFFECTING ALFALFA-GRASS ASSOCIATIONS

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ABSTRACT

An alfalfa (*Medicago sativa* L.)-grass association is not a stable ecosystem and requires management techniques to maintain the balance of species. The grass and the legume compete for water, light, and nutrients with competitive relationships changing from one season of the year to another. Cool-season perennial grasses differ somewhat in competitive ability with alfalfa but none compete as strongly as warm season grasses, particularly when grazed. Successful competition of alfalfa with grasses requires cutting at hay stage or grazing rotationally. Development of grazing-tolerant cultivars has greatly improved the competitive ability of alfalfa with grasses in pastures. Management of an alfalfa-grass association generally requires favoring the alfalfa by maintaining a favorable soil pH, high levels of P and K, managing light in the sward by good cutting or grazing practices, and selecting a cultivar with the greatest competitive potential.

INTRODUCTION

Most of the alfalfa grown in the USA is planted as a monoculture (Tesar and Marble 1988). This suggests that alfalfa-grass associations are of little importance. However, increased sodseeding of alfalfa for pasture and the normal encroachment of grasses into weakened older alfalfa stands makes this topic of considerable importance in making management recommendations. An understanding of the relationships in this association is essential to maintain reasonable stability of this ecosystem.

SOME GENERAL RELATIONSHIPS WITHIN THE ALFALFA-GRASS ASSOCIATION

A grass-legume association does not function as a stable climax ecosystem since it is artificial and man-made (Haynes 1980). Management techniques such as species, date and density of seeding, fertilizer, time and height of defoliation, animal stocking rates, and pesticides greatly affect the balance of grass and legume in the association. Even when alfalfa is planted in monoculture, it seldom remains such but is invaded by grasses and sometimes other plants. This new association is a combination of the inherent genetic factors of the alfalfa and the grass as well as the response of the alfalfa and grass to environmental factors. O'Connor (1967) describes this relationship as "the sociability" of alfalfa or its ability to survive and grow in the company of plants of other species and its ability to benefit other plants in association with it. One part of this relationship is competition which occurs when two or more plants seek the same essential resources when the supply of those resources is less than the combined demand of the plants (Donald 1963). Water, light, and nutrients are the most consistently sought resources in competition (Harper 1977). Competition is not restricted to one factor alone and it may be greatly affected by changes in density, form, or function of competitor plants, or in the factors needed for growth (O'Connor 1967). Environmental factors change over the growing season and affect the competitive relationships of the grass and alfalfa differently from one time of the year to another.

Several reasons are given for planting grass with alfalfa: (a) Sometimes mixtures of alfalfa-grass will yield more than alfalfa alone. However, Chamblee and Collins (1988) concluded that mixtures may or may not yield more than pure stands of alfalfa and that typical increases will average about 10 to 15%. Mooso and Wedin (1990) in Iowa concluded that alfalfa-grass mixtures offered little advantage over alfalfa monoculture when harvested for hay. (b) Grass in the mixture may reduce weed invasion.

(c) Grass will reduce soil erosion on hill sites. (d) Bloat potential in grazing animals is greatly reduced if grass is a significant component of alfalfa pastures. (e) The grazing season may be lengthened with a grass-alfalfa association, particularly if the grass is complementary in growing season to the alfalfa and not competitive with it. In some climates, a winter cereal can be drilled into the alfalfa to provide grazing during the dormant season when alfalfa growth is low.

Planting alfalfa into grass pastures offers several advantages: (a) provides symbiotic nitrogen fixation to enhance grass growth; (b) improves nutritive quality of forage; and (c) furnishes forage to grazing animals during summer when cool season perennial grasses are less productive. Consequently, sodseeding of alfalfa into established cool season perennial grass pastures is becoming a more common practice. This discussion will focus on environmental factors as they affect productivity and stability of the alfalfa-grass association. Inherent or genetic factors will be discussed as they interact with environmental effects.

Plant Nutrients

Alfalfa is commonly recognized as being intolerant of soil acidity and having a high requirement for Ca, thus the common recommendation of liming the soil to pH 6.5. When this is not done, grasses can be expected to quickly dominate alfalfa as they are generally more acid-tolerant species. Where soils have very acid subsoils with high levels of toxic aluminum, liming the surface soil has no effect on the subsoil, restricting root development of alfalfa (Sumner et al. 1986). Under these conditions, common in the southeastern USA, roots of many grasses can penetrate more deeply than alfalfa to extract soil water, giving the grass a competitive advantage. Surface-applied gypsum will ameliorate the Al toxicity and supply Ca in the acid subsoil, allowing deeper rooting by alfalfa.

Grasses compete more strongly than alfalfa for K, giving them a competitive advantage when this element is limiting (Blaser and Brady 1950, Hunt and Wagner 1963, McLeod and Bradfield 1963). Thus, under conditions of low K the grasses can be expected to dominate alfalfa in a mixture. Although K gives the most dramatic effect on alfalfa-grass competition, low levels of P and S also reduce the competitive ability of alfalfa with grass (Harris et al. 1966).

Nitrogen fertilization would be expected to favor grass in an alfalfa-grass mixture. A typical example of this is a reduction of alfalfa plants in an alfalfa-orchardgrass (*Dactylis glomerata* L.) hay-cut mixture with increasing rates of N (Parsons 1958). In contrast, alfalfa dominated bermudagrass [*Cynodon dactylon* (L.) Pers.] in mixtures even when heavily fertilized with N (Brown and Byrd 1990). Although alfalfa percentage in the forage decreased during summer, the early spring growth of alfalfa during the cool season and shading of the bermudagrass resulted in alfalfa dominance when cut for hay over three years. In another alfalfa-bermudagrass mixture study (Stringer et al. 1994) cut at 35-d intervals, N fertilization did not aid in retaining the grass in the mixture unless the alfalfa row spacing was increased. In a 3-yr study at three locations, N fertilization at 56 kg N/ha increased total yield of alfalfa-tall fescue mixtures but did not affect percentage alfalfa in the forage (Hoveland et al. 1995).

Temperature

Alfalfa declines in production during summer, particularly in regions with high night temperatures which cause high respiration rates. This is not a serious problem with an alfalfa monoculture or in mixtures with cool season perennial grasses which are also adversely affected by high temperatures. However, warm season perennial grasses have the potential to dominate mixtures if they are grazed or

harvested frequently during the hot months. In a review by Clarkson et al. (1991), it was concluded that alfalfa-tropical grass mixtures were more stable in colder areas than in hotter wetter coastal areas of Queensland, Australia. They attributed this to the long hot season and more alfalfa diseases which favored grasses in the coastal region.

Water

Alfalfa originated in the mountainous region of Transcaucasia, Asia Minor, and adjoining areas of northwestern Iran which have hot, dry summers (Michaud et al. 1988). Although daily evapotranspiration rates of alfalfa are similar to those of other crops with full ground cover, the total water use of alfalfa is high because of its long productive season (Sheaffer et al. 1988). Where soil conditions are favorable, alfalfa roots may penetrate to a depth of 1 to 2 m which is greater than that of most cool season perennial grasses. The favorable competitive performance of alfalfa when grown with orchardgrass results not only from alfalfa obtaining water at greater depths than grasses but also from the equal competition with the grass for available moisture in the upper soil levels (Chamblee 1958).

Supplemental irrigation of orchardgrass-alfalfa in a humid climate favored the grass more than the legume (Ward et al. 1966). Likewise, alfalfa stands thinned in rotationally grazed tropical grass pastures in eastern Australia when supplementally irrigated and during wet seasons (Cameron et al. 1990). In both cases, supplemental irrigation favored the grass at the expense of the deep-rooted alfalfa. Alfalfa roots in many non-irrigated soils would normally grow and extract moisture at greater depths than cool season grasses except in subtropical soils where acid subsoils inhibit alfalfa root development.

Light

Light often is the most limiting factor in competition in a grass-alfalfa mixture. Individual leaf efficiency in utilization of light was highest for bermudagrass, lowest for orchardgrass, and intermediate for alfalfa (Brown et al. 1966). The wide differences in light utilization by individual leaves of these species are impressive but often mean little in the competitive situation of a mixed species sward. The amount of light received by an individual leaf is affected by shading of one leaf by another. The most successful plant is not necessarily the one with the highest individual light efficiency or the most foliage but the plant which has its foliage in an advantageous position relative to the foliage of its competitors for light (Haynes 1980).

Alfalfa is highly responsive to light with the optimum for maximum growth rate over twice that for red clover (*Trifolium pratense* L.) and perennial ryegrass (*Lolium perenne* L.) (Blackman and Black 1959). The foliage architecture of alfalfa with its angled arrangement of leaves on an erect plant is an important factor in its ability to capture light. The leaf area index of alfalfa continues to increase after the index at which interception of light by the canopy is complete (Brown and Blaser 1968). The leaf area index values for alfalfa are higher than for many other forage species, reaching 10 or 11 (Smith et al. 1964).

Competition for light can be a problem during establishment when alfalfa is planted with a companion crop such as oats (*Avena sativa* L.) or if weed infestation is heavy (Tesar and Marble 1988). Satisfactory alfalfa establishment generally occurs under these conditions when the oats are harvested for silage or grain and weeds are controlled with a herbicide or mowed (Sheaffer 1989). Once established, mixed stands of alfalfa and cool season perennial grasses harvested two or three times annually tend to be dominated by alfalfa as long as the legume stands are

good (Haynes 1980). However, cool season-active grasses initiate growth earlier than alfalfa and may dominate early season production (O'Conner 1967). In such a situation or competition for insufficient K, many alfalfa crown buds may fail to develop because of shading and result in grass domination (Chamblee and Lovvorn 1953). Generally, well-fertilized alfalfa-cool season grass mixtures tend to become alfalfa dominated during summer as the grass is less competitive (Haynes 1980). In the case of bermudagrass, a warm season perennial grass, alfalfa begins growth much earlier in spring than the grass and results in alfalfa dominating the mixture when it is harvested at hay stage (Brown and Byrd 1990). Bermudagrass is very intolerant of shade and the tall canopy of alfalfa dominates the mixture unless it is cut or grazed frequently, allowing light to stimulate growth of the grass (Bates et al. 1996).

Shading of alfalfa reduces nodulation and nitrogen fixation (Pritchett and Nelson 1951). Roots of alfalfa are more sensitive than top growth to shading (Gist and Mott 1957). Restriction of alfalfa root growth by shading in a grass-alfalfa mixture can reduce the ability of the legume to obtain moisture at greater soil depths, thus limiting its normal competitive advantage. The influence of light in alfalfa-grass mixtures is complex and many factors interact such as grass species, seasonality of growth, dormancy level of the alfalfa cultivar, soil fertility, subsoil acidity, soil moisture, and cutting or grazing management. For instance, Miller et al. (1984) found that light was more evenly distributed in mixtures than in pure alfalfa and that grass competition for light was greatest at first harvest and declined at successive harvests.

Grass Species

Grass species differ in competitive ability with alfalfa in mixtures. Most all of these studies have been harvested three or four times annually, a management system which should favor alfalfa in a mixture. With cool season perennial grasses under a hay cut system, orchardgrass has generally been one of the strongest competitors with alfalfa. In Wisconsin, Smith et al. (1973) found orchardgrass and reed canary (*Phalaris arundinacea* L.) persisted much better than timothy (*Phleum pratense* L.) or smooth bromegrass (*Bromus inermis* Leyss.) with alfalfa. Casler (1988) ranked grasses for vigor and ground cover in mixture with alfalfa as orchardgrass>smooth bromegrass>annual ryegrass (*Lolium multiflorum* Lam.) and perennial ryegrass. In another Wisconsin study (Casler and Walgenbach 1990), orchardgrass and tall fescue (*Festuca arundinacea* Schreb.) persisted better than timothy, smooth bromegrass, reed canary, and annual and perennial ryegrass in mixture with alfalfa. With a three cut system, orchardgrass persisted but timothy and smooth bromegrass were eliminated in alfalfa mixtures (Wolf and Smith 1964). Annual ryegrass was a better competitor with alfalfa than perennial ryegrass while summer production of timothy was zero in Pennsylvania (Jung and Shaffer 1993). In the more stressful summer environment of North Carolina, tall fescue depressed the growth and persistence of alfalfa more than orchardgrass in mixture even though the two grasses were equally productive (Chamblee and Lovvorn 1953). In Georgia, alfalfa drilled into five grass sods over a 3-yr period had poorer stands and yield in endophyte-free or -infected tall fescue than orchardgrass, Kentucky bluegrass (*Poa pratensis* L.), or reed canarygrass (C. S. Hoveland, unpublished data). The reason for this is unclear but it may be related to allelopathic characteristics of tall fescue (Smith and Martin 1994).

Rotational grazing studies have given mixed results on grass species differences. Jackobs (1952) in central Washington found that alfalfa persisted well with Kentucky

bluegrass, smooth bromegrass, orchardgrass, tall fescue, perennial ryegrass, and tall oatgrass [*Arrhenatherum elatius* (L.) Presl] over four years. In Pennsylvania, orchardgrass was much more competitive than perennial ryegrass with alfalfa when grazed 12 d with 36-d rest periods (Jung et al. 1982). After two years of grazing, perennial ryegrass mixtures had 53% more alfalfa plants than the orchardgrass mixtures, possibly a result of the much greater palatability of the ryegrass. In a Wisconsin rotational grazing study with sheep, persistence of smooth bromegrass and orchardgrass were superior to timothy in mixture with alfalfa but none of the grasses persisted well by the third year (Hamilton et al. 1969). Alfalfa stands remained excellent. Cool season grasses such as tall fescue and phalaris (*Phalaris aquatica* L.) are even less persistent with alfalfa in subtropical environments as they are rapidly invaded by warm season perennial grasses (Ivory, 1982).

Bermudagrass, a warm season perennial, is a vigorous competitor with alfalfa in summer but because of early season growth and more rapid regrowth by the legume and shading by the grass, alfalfa tends to dominate the mixture (Brown and Byrd 1990, Stringer et al. 1994). However, when the mixture is grazed without rotation the bermudagrass soon dominates the mixture (Bates et al. 1996). In a review by Leach and Clements (1984) they conclude that the problem of stable alfalfa-warm season grass pastures is not grass survival but rather keeping the alfalfa in the pasture. Among the problems in maintaining stable alfalfa-warm season perennial grass mixtures are the high summer growth rates of the grass and the lower palatability of the grass. Thus, management of the mixed pasture becomes even more critical in this environment to favor the alfalfa.

Cutting Management

Maintaining a stable alfalfa-grass mixture is related to harvesting when the alfalfa is in the early bloom stage or later (Dotzenko and Ahlgren 1950). Cutting at an earlier stage or more frequently will reduce the vigor of the alfalfa and increase the proportion of grass in the forage (Comstock and Law 1948, Sprague et al. 1964). Cutting five times, as compared to three times annually reduced alfalfa in mixtures and the total yield (Wolf and Smith, 1964). With a 3-cut system, orchardgrass persisted well but smooth bromegrass and timothy were nearly eliminated in two years. In contrast, Smith et al. (1973) found that alfalfa maintained excellent stands with orchardgrass, reed canarygrass, and dominated timothy and smooth bromegrass with 2-, 3-, or 4-cut systems and either a high or low stubble. Tall fescue was nearly eliminated with a 2-cut system at a 4-cm stubble but not at a 10-cm stubble. After three years of cutting mixtures of tall fescue and a grazing-tolerant alfalfa cultivar, alfalfa constituted over 50% of the mixture at 4- and 6-wk cutting intervals and over 25% at the 3-wk interval (Hoveland et al. 1995). Obviously, the species of cool season perennial grass and alfalfa cultivar will affect alfalfa persistence but more frequent cutting can be expected to reduce alfalfa in mixtures.

Frequent cutting of alfalfa-warm season perennial grass mixtures results in a rapid decline of the legume since these grass species are so much more competitive than cool season perennial grasses (Leach and Clements 1984). When bermudagrass seed were broadcast on established alfalfa, the grass dominated the stand after two years when harvested at 2-week intervals but at 4-week cutting intervals there was virtually no bermudagrass (Hoveland et al. 1996). Shading by rapid alfalfa regrowth probably prevented establishment of bermudagrass.

Grazing Management

Generally, pastures of alfalfa-grass mixtures have furnished higher animal daily gains than grass monocultures (Van Keuren and Matches 1988). The problem in grazing alfalfa or alfalfa-grass mixtures is to maintain stands and productivity of the legume over a period of several years. Continuous stocking of pastures will result in a reduction in vigor and stands of alfalfa. Thus, it has long been recognized that persistence of alfalfa is dependent on some method of intermittent or rotational stocking where the pasture is grazed for 4 to 14 days followed by a rest period of 4 to 5 weeks (Leach and Clements 1984, Van Keuren and Matches 1988). Thus, the defoliation management for grazed alfalfa is similar to that when harvested for hay. However, alfalfa cultivars that do well in pure stands may not perform the same in grass mixtures. Trials on North Dakota rangeland showed that short-term testing in pure stands did not identify strains that performed well in mixtures with grasses (Berdahl et al. 1989). Similar results were obtained with smooth bromegrass where pure stands of alfalfa did not identify the strain most persistent in a mixture (Bittmen et al. 1991).

When a mixture of grass and alfalfa are grazed, new problems of competition arise between species and potential differences in palatability to the grazing animal. When grazed rotationally with a 4-paddock method in Washington state, alfalfa comprised 64% of the mixture in orchardgrass and 49% in tall fescue after three years (Van Keuren and Heinemann 1958). In Pennsylvania, orchardgrass was much more competitive than perennial ryegrass with alfalfa when grazed 12 days with a 36-day rest period using a 4-paddock method (Jung et al. 1982). With a 4-paddock rotation using lambs on alfalfa with smooth bromegrass, timothy, or orchardgrass in Wisconsin, none of the grasses persisted well by the third year (Hamilton, et al. 1969) Taking an early hay

cut followed by grazing with a 3-paddock (20 day recovery) rotation maintained alfalfa in the mixture much better than rotational stocking all season in Tennessee (Van Horn et al. 1956). Grazing alfalfa-cool season perennial grass mixtures during wet years resulted in lower animal daily gains and reduced alfalfa in the sward as compared to drier years (Whitear et al. 1962, Wilman 1977).

Maintaining alfalfa in pastures with warm season perennial grasses is much more difficult than with cool season species. The high summer growth rates and lower palatability of warm season perennial grasses as compared to cool season grass species are cited as major problems in maintaining a stable mixture (Leach and Clements 1984). Christian and Shaw (1952) in southeast Queensland, Australia rotationally grazed alfalfa-rhodesgrass (*Chloris gayana* Kunth) for two weeks on and eight weeks off but were unable to maintain a good stand of legume. Heavy stocking in the rotation was necessary to maintain some alfalfa in the mixture. However, even a low alfalfa plant density of 2 to 4 plants/m^2 enhanced beef production. In a drier region of Queensland, rotationally grazed pastures of alfalfa and rhodesgrass or green panic (*Panicum maximum* var. *trichoglume* Eyles.) resulted in loss of the alfalfa after two years (Silvey et al. 1978). The difficulty of maintaining alfalfa in rhodesgrass is illustrated by the 6-yr study in Queensland where none of six rotation grazing methods with sheep were entirely successful (Leach 1979). Even in pure stands of alfalfa, encroachment of aggressive warm season perennial grasses is a problem whether continuously or rotationally stocked. However, under continuous stocking in Georgia, encroachment by bermudagrass was minor at low grazing pressure but severe at high grazing pressure (Bates et al. 1996). Leach and Clements (1984) conclude from their review that year-around rest periods of at least five weeks are needed in the subtropics

to maintain alfalfa in a productive state.

The recommendation that alfalfa in pure stands or mixtures must be stocked rotationally to allow a 4- to 5-wk rest period between grazings mimics that for hay production. This is not surprising since nearly all alfalfa cultivars were selected under a hay harvest system. However, selection under continuous close grazing for two to three years has successfully developed grazing-tolerant cultivars without sacrificing yield potential for hay production (Smith and Bouton 1993). There is very limited data comparing alfalfa cultivars in mixture with a grass under grazing. The grazing-tolerant cultivar 'Alfagraze' was much more persistent than two hay-type cultivars under severe continuous grazing in mixed stands with tall fescue (Smith et al. 1992). Alfagraze persistence was also superior to a hay-type cultivar in continuously grazed pastures where bermudagrass had encroached (Bates et al. 1996). Even though a grazing-tolerant cultivar can survive better than hay type cultivars under continuous stocking, it would be advisable to utilize a rotational method to reduce encroachment by grasses, particularly in areas where warm season perennial grasses are common. Where alfalfa is utilized to improve the diets of growing animals on warm season perennial grass pastures, a better approach to maintaining alfalfa stands would be to plant the alfalfa in a separate pasture and allow animals on the grass pasture to limit or creep graze the alfalfa.

SUMMARY

Grass may be planted with alfalfa to extend the productive season, improve forage nutritive quality, reduce bloat potential, and reduce weed encroachment. Forage yield is increased only slightly or not at all by inclusion of grass with alfalfa. A companion grass often creates new competition problems for alfalfa especially in

respect to K, light, high temperature, and water. The competition problems are accentuated with warm season as compared with cool season perennial grasses. Cutting management of mixtures must favor the alfalfa by harvesting at early bloom stage. Likewise, grazing of alfalfa-grass mixtures must allow a 4- to 5-wk rest period between grazings in a rotational method to prevent dominance by the grass. Cultivars selected for grazing tolerance under severe grazing in monoculture also appear to be more competitive and persistent in mixture with grasses. Future development of pasture-type alfalfa cultivars should include selection of germplasm under grazing in mixture with grasses.

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OVERVIEW OF THE ROLES AND IMPORTANCE OF LEGUMES IN FORAGE/LIVESTOCK SYSTEMS

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ABSTRACT

As compared to grasses alone, legume/grass mixtures offer many advantages in forage/animal systems including biological nitrogen fixation, high forage quality, increased yields, longer seasonal distribution of growth, improved soil tilth, and offsetting of certain livestock disorders. Although these benefits have long been recognized, it can be argued that legumes have not been used in forage/animal systems to the extent they should have been. This paper will provide a discussion of benefits resulting from the use of forage legumes, an assessment of reasons why many producers have not used them, and suggest reasons as to why it is becoming even more important and justifiable to use them in the USA. Factors that will continue to influence greater use of legumes include an increased emphasis on sustainable agriculture, introduction of improved species and cultivars, higher cost of nitrogen fertilizer, increased feasibility of using alfalfa as a grazing crop, greater environmental awareness, more emphasis on grazing management, technological advances in fencing and no-till planters, and economic considerations regarding forage/livestock production.

INTRODUCTION

Forage legumes have played an important role in animal agriculture throughout the world. Yet, despite their obvious importance and the contributions they have made in the USA and elsewhere, it seems that they are not used to the extent that they really should be.

The inspiration for this paper was provided by the observation that a number of recent developments seem likely to have a long range impact on the extent to which legumes may be used in forage programs in the USA in the future. The timing therefore seems appropriate for an objective assessment of the benefits legumes offer, the roles they can play in forage agriculture, and the outlook for their use in the future.

BENEFITS OF LEGUMES

The primary benefits associated with growing legumes have long been known, and they are frequently mentioned in extant literature. These benefits include increased forage yield, improved forage quality, and biological nitrogen fixation (Hoveland 1989, Matches 1989, Ball et al. 1991, Lacefield et al. 1993a and b, Sheaffer et al. 1993, Beuselinck et al. 1994).

In addition, growing legumes with grass can improve seasonal distribution of forage growth and often improve animal performance and overall economic return over grass alone (Petritz et al. 1980, Burns and Standart 1985, Lacefield et al. 1989, Marten 1989, Undersander 1993, Lacefield 1995). The myriad of possible combinations of various legumes with a large number of grasses in differing climates under assorted management schemes for the purpose of accomplishing a wide range of objectives virtually defies description.

Though there is widespread general knowledge among producers of the fact that legumes are beneficial in forage/livestock systems, their use patterns throughout the world suggest that they still are not fully appreciated. It appears that the future role of legumes may be even more important as we see reasons to further exploit these

special plants for their unique characteristics. A discussion of selected advantages offered by forage legumes, provided in no particular order, follows.

Improved Forage Quality -- Growing legumes with grasses usually improves forage quality over grasses alone. This results in increased palatability, intake, digestibility, nutrient content, and ultimately animal performance (Knight 1984, Miller 1984, Burns and Standert 1985, Matches 1989, Ball et al. 1991, Ball and Crews 1993, Lacefield et al. 1989, Lacefield et al. 1993a and b, Sheaffer et al. 1993, Undersander 1993).

Nitrogen Fixation -- The relationship which exists between forage legume plants and *Rhizobium* bacteria is truly unique. The fact that this symbiotic relationship results in the conversion of atmospheric nitrogen (N) into a chemical form that the legume plant uses to make protein and other N containing compounds contributes greatly to the agronomic value of legumes in forage systems. The importance of this to grass/legume mixtures is that in addition to being available to the legume, some of the "fixed" N is also available to grass plants growing in association with the legume (Burns and Standert 1985, Lacefield et al. 1989, Marten 1989, Matches 1989, Ball et al. 1991, Lacefield et al. 1993 a and b, Lacefield 1995). The value of N fixed depends on legume species and price of commercial N fertilizer (Table 1).

Increased Forage Yields -- The total yield of forage per acre from grass-legume mixtures is usually increased over grass alone. For example, studies conducted over many years at the University of Kentucky have shown that red clover (*Trifolium pratense* L.) grown with tall fescue (*Festuca arundinacea* Schreb.) produces more total yield than tall fescue fertilized with 82 kg/N/ac (Lacefield et al. 1989).

Improved Seasonal Distribution of Growth -- Most cool-season grass growth occurs during spring and autumn. In most portions of the USA, forage legumes generally make more summer growth than cool-season grasses. Thus, growing grasses and legumes together can improve the seasonal distribution of a pasture and provide more summer growth (Knight 1984, Burns and Standert 1985, Lacefield et al 1989, Lacefield et al 1993 a and b, Sheaffer et al. 1993, Lacefield 1995).

In much of the southern portion of the USA, warm season perennial grasses dominate the pasture acreage. Seeding of cool season annual legumes into bermudagrass or other warm season grasses permits, without costly N fertilizer, production of quality feed during winter and early spring when pastures would otherwise be unproductive (Knight 1984, Burns and Standert 1985, Lacefield et al. 1989, Ball et al. 1991, Lacefield et al. 1993 a and b, Sheaffer et al. 1993).

Offsetting of Disorders -- Legumes can play an important role in offsetting livestock disorders caused by some forage grasses. In a recent survey of two southern states (Lacefield et al. 1993), "growing legumes with tall fescue" was found to be the number one strategy used by beef producers to cope with toxicosis caused by the tall fescue endophyte (*Acremonium coenophialum* Morgan-Jones and Gams). Grass tetany is another animal disorder reduced or eliminated by the presence of legumes in the diets of grazing livestock. (Lacefield et al. 1980, Lacefield et al. 1993 a and b).

Improved Soil Tilth -- Many legume species have extensive root systems and/or shed a substantial quantity of leaves which ultimately become part of the top soil. Thus, soil tilth is usually improved more by legumes than by grasses (Ball et al. 1991, Lacefield et al 1993 a and b).

Better Seedling Vigor -- In general, legumes have higher seedling vigor than grasses. This characteristic permits more rapid development of ground cover than would be the case with less vigorous seedlings (Lacefield et al. 1993 a and b).

Improved Production of Other Crops in Rotations -- In addition to furnishing N for succeeding crops, some legumes improve soil physical traits as a result of their characteristic taproot-type root systems. The taproots of some legumes penetrate the soil quite deeply. When this occurs, the root channels which are developed benefit subsequent crops grown in rotation with legumes or legume-grass mixtures (Burns and Standert 1985, Knight 1984, Lacefield et al. 1989, Matches 1989, Ball et al. 1991, Lacefield et al. 1993 a and b).

Nectar and Pollen for Bees -- Legumes are vitally important to the bee and honey industry because they furnish a primary food source for honey bees. Alfalfa remains the number one honey crop in the USA (Lacefield et al. 1993 a and b).

Environmental Acceptability -- Legumes and their symbiotic relationship with *Rhizobium* bacteria result in the production of slow release N rather than large suddenly-available quantities which would be more likely to be released into the environment. Legumes also furnish food for beneficial insects and wildlife.

Reduced Risk -- In addition to complementing grasses in many ways, having a mixed sward of grass and legumes constitutes a lower risk situation than having a pure grass sward. A single disease or insect pest is much less likely to devastate mixed grass/legume forage stands.

ANIMAL PERFORMANCE

Grass pastures vary greatly in forage quality at different times of the year but legumes, with their higher quality, can help buffer this problem and improve animal performance. For example, cattle producers have long known and recognized the value of having even small amounts of common [*Lespedeza striata* (Thunb.) H. & A.] or Korean (*Lespedeza stipulacea* Maxim.) annual lespedeza in pastures during late summer when nutritive quality of cool season grasses declines. As another example, overseeding 'Coastal' bermudagrass [*Cynodon dactylon* (L.) Pers.] with annual clovers in south Alabama as compared to grass plus 45 kg N/acre increased grazing dates by a month, cow gain 0.4 kg/day, and calf gain 0.17 kg/day over a 3-year period (Hoveland et al. 1977).

Probably the strongest case for legumes can be made where endophyte-infected tall fescue is the base pasture for cow-calf operations. The vast majority of the 35 million acres of tall fescue in the USA is endophyte-infected. Livestock production losses, primarily associated with beef cattle, from fescue toxicosis are estimated at between $500 million and $1 billion annually (Ball et al. 1993 a and b). The value of legumes in reducing these losses is illustrated by a 3-year study in southern Indiana where red clover and white clover (*Trifolium repens* L.) on infected versus N-fertilized tall fescue increased cow pregnancy by 20% and increased calf daily gain by 0.23 kg/day.

Adding more N fertilizer to endophyte-infected tall fescue does not alleviate the toxicity problem and often makes it worse. Replanting infected pastures with endophyte-free seed is expensive and incurs new management problems. Overseeding infected pastures with clover or other legumes is inexpensive and a realistic solution to poor animal performance (Ball et al. 1993 a and b, Lacefield et al. 1993 a and b).

ECONOMICS OF USING LEGUMES

The use of legumes can have an enormous impact on the economics of animal agriculture. Nutrition is generally recognized as being the primary limiting factor in livestock production, and legumes on the average provide higher levels of nutrition than do grasses.

Using beef cattle production as an example, better nutrition results in more milk production from beef cows, higher weaning weights from calves, and increased likelihood of a higher percent calf crop. These factors obviously impact on the gross income from a beef cow-calf operation.

When *Rhizobium*/legume symbiosis results in the fixation of substantial quantities of N, producers can avoid or reduce expenditures for commercial N fertilizer. Nitrogen fertilizer typically accounts for 20 to 40% of the expenses itemized in grass pasture budgets.

Seed costs per acre for clovers, the most frequently-used legumes in pasture situations, is usually in the range of $10 to $20 per acre. Other costs associated with establishing clovers depend on the site, situation, and method of seeding. The use of legumes in pasture programs has dual beneficial effects. When legumes are present in the pasture sward, animal performance goes up, while the expenses associated with forage production go down.

FACTORS LIMITING LEGUME USAGE

The fact that legumes offer numerous attributes in forage programs, as discussed in the preceding portion of this paper, is generally accepted. Why, then, are they not in as widespread use as many legume enthusiasts think they should be? We believe there are five primary reasons why producers have not used legumes more than they have.

Inexpensive Nitrogen--During most of the time since World War II, N fertilizer has been relatively inexpensive. For convenience and simplicity, producers have used grasses and stimulated forage growth with commercial N fertilizer. Increased cost of N fertilizer would be a compelling incentive to use legumes to a greater extent.

Persistence/Dependability--Forage producers typically place a high value on persistence and dependability, and legumes are simply not as persistent as many forage grasses (Hoveland 1989). Frustration over inability to maintain legume stands is probably a primary reason why many livestock producers have not used legumes more than they have.

Lack Of Appreciation Of Legume Benefits--In some cases it may be that producers do not fully understand the benefits associated with growing legumes, particularly from an economic standpoint. While it is probable that almost all producers realize that legumes are beneficial and they like to see them in their pastures, it seems that at least some producers don't fully appreciate how beneficial they really are.

Higher Management Requirement--Forage legumes require more management than forage grasses (Van Keuren and Hoveland 1985). As a result, many producers simply decide that it's too much trouble to grow them. It appears that many producers find it easier to grow grasses, periodically apply N fertilizer to stimulate forage growth, and not be concerned about trying to keep legumes in the forage stand.

Bloat--Bloat is a major concern for many producers and often causes them to hesitate (or even refuse) to use legumes. The prospect of finding dead animals in a pasture is, understandably, unpleasant and thus is likely to cause over-reaction which impacts negatively on legume usage.

OUTLOOK FOR LEGUME USAGE IN THE FUTURE

Given the fact that many producers have not used legumes in forage programs in the past, it is logical to consider whether there is reason to believe that we will see more legume usage in the future. The remainder of this paper will be an attempt to assess the long term outlook for forage legumes in the USA. While we cannot predict the future, we know that present day trends or developments often suggest likely future scenarios. Examination of some current trends and developments which seem relevant to the use of legumes is therefore appropriate.

In recent years we have seen an emphasis on "sustainable agriculture." While this term may mean different things to different people, most everyone seems to agree that legumes certainly figure into the sustainable agriculture picture because of the energy efficiency they provide as compared to N fertilizer. For example, only about 73 percent of the fossil energy needed to produce corn (*Zea mays* L.) is required to produce forage legumes (Russell et al. 1992).

The use of legumes in rotation with non-leguminous crops has long been known to be an economically advantageous practice (Bailey et al. 1930). Despite knowledge of the advantages of interruption of pest cycles as well as the provision of biological nitrogen for following crops, during the past thirty years crop rotation has not been practiced in the USA to the extent that many agronomists feel it should have been. Present emphasis on sustainable agriculture has renewed enthusiasm for use of rotation schemes, particularly those which involve legumes.

The production, and also the handling, of N fertilizer requires substantial energy inputs. Use of large quantities of N fertilizer increases the energy inputs into agricultural production not only at the farm level but also impacts greatly on national energy requirements.

We have also observed unprecedented environmental awareness in recent years. National surveys have revealed that a high percentage of Americans have strong feelings regarding environmental issues. Environmental consciousness is something that we have to take quite seriously and it certainly seems to be a trend which is not likely to, and should not, go away.

Part of that environmental awareness pertains to water quality, a top national priority. There is increasing concern about the use of commercial fertilizers, especially N fertilizers, primarily because of the possibility of contamination of surface and/or ground water.

Because legumes offer a slow release form of N, they are viewed as constituting a more environmentally-friendly approach to providing N for grass growth than the practice of applying commercial N fertilizer in large quantities. While governmental programs do not at present necessarily encourage the use of legumes, it isn't difficult to believe that in the future this could happen as a result of political pressure relating to the environment. If limits were to be placed on N applications, it could be argued that the public would be better served to put a priority on the application of N to human food crops rather than on forage crops.

An area of scientific investigation about which we can be particularly enthusiastic is the introduction of new forage legume species and the development of new forage legume varieties. Such research offers great potential for identifying forage legumes which are well suited for specific situations.

Plant breeders have identified persistence as a priority in development of improved

legume cultivars (Sheaffer et al. 1988, Beuselinck et al. 1994). In order for legume persistence to be improved, at least one of the following characteristics has to be incorporated: (1) the ability of the plant to reproduce from seed has to be increased; (2) individual plants have to live longer; or (3) the ability of plants to reproduce by rhizomes or stolons has to be incorporated or improved. Recent success stories involving each of these can serve as examples.

The recent release of 'Overton R-18' rose clover (*Trifolium hirtum* All.) exemplifies the advent of a useful reseeding legume cultivar (Smith et al. 1992). On droughty soils along the Gulf Coast, this annual clover has much potential for improving forage quality and quantity and providing some biological N for warm season perennial grass pastures. The fact that this cultivar makes a high percentage of hard seed allows it to persist well in hostile environments (Evers and Dorsett 1986).

A development which illustrates the second method of prolonging legume stands is the release of the alfalfa (*Medicago sativa* L.) cultivar 'Alfagraze' (Bouton et al. 1991), which is considered by many people to constitute a breakthrough with this important forage species. The key characteristic of this cultivar is its improved ability for increased individual plant life; specifically in this case, increased individual plant life under grazing (Brummer and Bouton 1991).

This is a significant development, especially for the Southeast. In the Southern region it has long been known that alfalfa can be grown quite well; the main problem has been expense and rain damage risk associated with haymaking. With grazing tolerant varieties now a reality, producers have the option of cutting hay when the weather is favorable, but otherwise harvesting it relatively cheaply by grazing.

In view of the concerns which producers have regarding legume bloat, it is worthwhile to mention that while most producers traditionally have grown alfalfa which is to be harvested for hay or silage in pure stands, there is much reason to consider growing grazing tolerant alfalfa in combination with grass. This reduces the likelihood of bloat while providing biological N for grass growth.

An interesting example of increasing the ability of a legume plant to reproduce vegetatively is the incorporation into birdsfoot trefoil (*Lotus corniculatus* L.) of rhizome-forming ability (Beuselinck 1992). The anticipated future commercially availability of more persistent cultivars of this widely adapted, non-bloating perennial legume will be a welcome addition on many farms, particularly in the eastern USA.

There are numerous other legume species and/or varieties which could be used as examples. The point is that, while the identification of new useful species and the development of new cultivars is sometimes frustratingly slow, we are making progress with regard to improved legume persistence.

In addition, there are almost certainly additional legume species or germplasm in the world which have not yet been identified which can be useful in the USA. In particular, scientists now have access to areas in the former Soviet Union where there are likely to be legume forage plants which can be useful to us, and screening of accessions is underway (Smith and Hoveland 1994).

There is also another trend of which Extension Agronomists are quite aware and that is a change in attitude among a substantial number of forage producers. A new breed of producer is springing up in our midst who think of themselves more as grass farmers rather than just as livestock producers. These individuals have increased

interest in forage management, particularly grazing management.

It is likely that the ready commercial availability of high tensile wire fencing has contributed greatly to the trend toward increased grazing management. This technology has made it increasingly easy and inexpensive for producers to erect fences, move animals, and do an overall better job of grazing management than was possible just a few years ago.

Advances with another type of technology has increased the feasibility of incorporating legumes into existing grass pastures, and that is the development of improved no-tillage grassland drills. Though such equipment was relatively uncommon on farms in many areas just a few years ago, numerous brands and models are now readily commercially available and many producers either own, or have access to, such drills today.

The possibility of legume bloat remains a concern, but if producers can become excited about improving grazing management, it is not unrealistic to believe that they can also learn how to confidently manage to avoid legume bloat. The importance of legume bloat should not be minimized, because it certainly can be a serious problem. However, it should be kept in perspective.

We contend that far more livestock have died from starvation or problems complicated by poor nutrition than have died from bloat and that the fear of bloat has actually been far more costly than bloat itself. If legumes are grown in mixtures and grasses and producers are willing to exercise a bit more management to prevent bloat, we are optimistic that this will become less of an obstacle to the use of legumes than it has been in the past.

Last but not least, economics seem more and more to favor the use of legumes. Figure 1 shows the consumer price index for N between 1960 to 1991 (Vroomen and Taylor 1992). The cost of N fertilizer is considerably higher at present than it was a decade or two ago, and the long-range outlook for prices in the future is not encouraging. As a result, today more and more producers are seeking ways to reduce their fertilizer bill.

SUMMARY AND CONCLUSIONS

In a pasture or hayfield in which the botanical composition includes a substantial stand of one or more legumes, the benefits that were discussed at the beginning of this paper are going to be realized. The benefits of using legumes in forage systems have not changed, nor will they change in the future.

What does seem to be changing is the value of those benefits and general recognition of them. Furthermore, and at least some of the obstacles which have prevented producers from seeking and realizing those benefits have changed or are changing as well.

The average age of cattle producers in the USA is over 60 years. Those of us who work with producers are soon going to have a new group of clients who are not so biased by their past experience. We are going to have opportunities for making real progress in the next few years in providing information regarding the value of legumes, how to establish and manage them, and how to avoid problems with bloat.

Forage legumes are agronomically feasible, socially acceptable and environmentally sound. They offer multiple advantages in pure stands, and legume-grass mixtures offer numerous benefits over straight grass fertilized with N.

Given the advantages which forage legumes offer, is there reason to think that we will see increased use of these unique plants in forage systems in the future? In view of an ever-increasing ability to obtain improved persistence of legumes in various situations, a social/political/economic climate which seems to favor increased use of legumes, and a producer clientele which seems increasingly inclined toward exercising the management legumes require, we believe the answer is a resounding yes.

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842.

Table 1. Value and amount of N fixed by selected legumes.

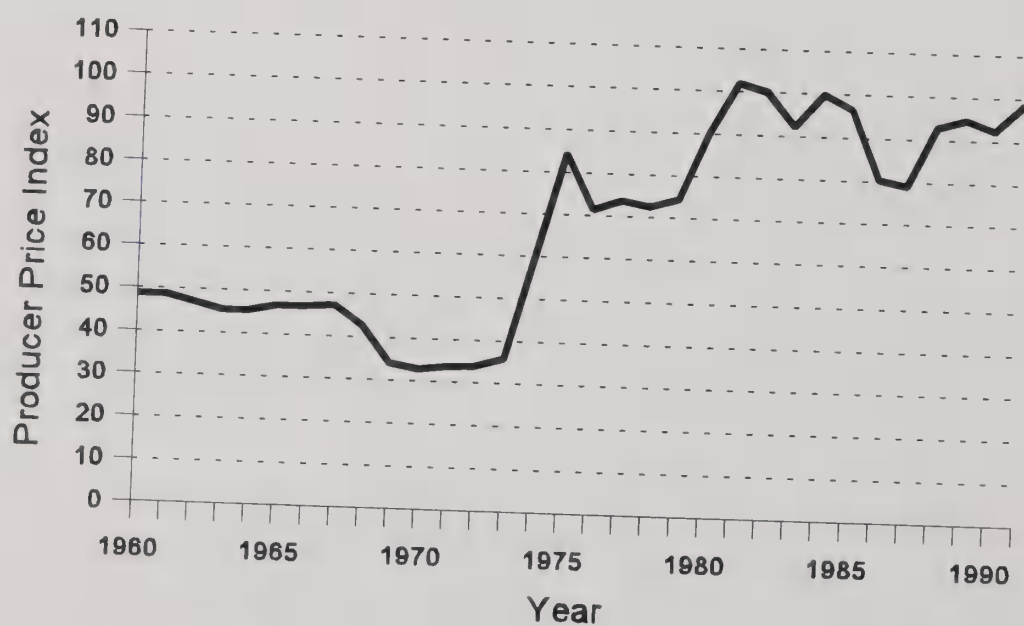| Crop	N fixed lb/A/year	N value, $, @	
		$.25/lb	$.30/lb
Alfalfa	200-300	50-75	60-90
Red Clover	100-200	25-50	30-60
Ladino Clover	100-150	25-38	25-38
Vetch, lespedeza and other annual forage legumes	75-150	19-38	23-45

Figure 1. Producer price index for nitrogen fertilizer, 1960-91.

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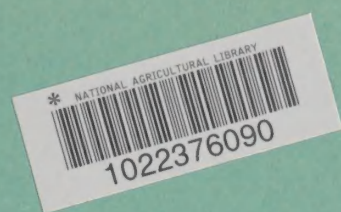Griffin, GA 30223

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